**Environmental Protection Department
Operations and Regulatory Affairs Division**

Health Risk Assessment for Hazardous and Mixed Waste Management Units at Lawrence Livermore National Laboratory

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Executive Summary

EXECUTIVE SUMMARY

Lawrence Livermore National Laboratory (LLNL) is a U.S. Department of Energy (DOE) research facility located in Livermore, California. It is jointly operated by the University of California and DOE. LLNL comprises two sites, the main Livermore site (Main Site) and Site 300. This health risk assessment pertains only to Main Site hazardous waste management operations. The facilities are presently operated under interim status pursuant to the Resource Conservation and Recovery Act (RCRA). The facilities are operated by LLNL's Hazardous Waste Management (HWM) Division in the Environmental Protection Department (EPD).

Lawrence Livermore National Laboratory (LLNL) has previously applied for a Hazardous Waste Storage and Treatment Permit for its hazardous waste management facilities at the Main Site. A prior health risk assessment was conducted for those operations in 1995, pursuant to 22 CCR 66264.601(c), entitled *Health Risk Assessment for Hazardous and Mixed Waste Management Units at LLNL* (1995 HRA) (LLNL, 1995). Subsequent to the publication and distribution of the 1995 HRA, it was determined that the RCRA Part B Permit Application should address the configuration that will exist when the proposed Decontamination and Waste Treatment Facility (DWTF) is operational. Therefore, this 1997 Health Risk Assessment (HRA) has been prepared in support of the revised permit application, and the scope includes the configuration of Hazardous Waste Management Facilities corresponding to the full operation of the DWTF.

The revised permit application, dated June 28, 1996, includes detailed descriptions of the waste generated at LLNL and the three hazardous waste management facilities at the LLNL Main Site, referred to as the Area 612 Facility, the DWTF Complex, and the Building 280 Facility. The Area 612 Facility and DWTF Complex contain treatment and storage units for hazardous and mixed wastes; the Building 280 Facility is a separate container storage area for hazardous and mixed waste. HWM staff process, store, package, solidify, treat, and/or prepare waste for offsite shipment and disposal, recycling, or controlled discharge to the sanitary sewer.

The health risk assessment involved a number of steps, beginning with the characterization of the sources of potential risk, or "source term assessment." The hazardous waste management facilities were evaluated with regard to their potential to produce atmospheric emissions. Two facilities were identified as sources: the DWTF Facility and the Area 612 Facility. Each of these two facilities has both a "stack" emission point and a general "area" emission source. Thirteen waste treatment units were evaluated for their contribution to emissions, and maximum throughput capacities were established. Each treatment unit was evaluated in terms of its air emission abatement equipment, such as HEPA filters and carbon adsorption, which reduce atmospheric emissions from the facilities.

Waste characteristics for each treatment unit were established by searching the Total Waste Management System (TWMS) database, which contains records of the chemical constituents of the wastes. These records describe the specific chemicals and their quantities in the waste streams. A total of 12,500 unique waste items were identified in the data search, which contained about 1,100 unique chemical names. Each chemical was described in terms of its properties and emission factors. Of these 1,100 chemicals, about 400 had associated toxicity values, about 50

were non-toxic, and about 650 were treated as "surrogates" with assigned toxicity values. The use of surrogates contributed to a conservative estimate of risk and, thereby, accounted for the types of changes in waste stream characteristics that are inherent in a research and development facility. With regard to liquid waste processing in the tank farm, and liquid waste transfers at the Area 612 Yard, some data developed for the 1995 HRA was incorporated into this 1997 HRA.

The potential for each identified chemical and radionuclide to be emitted was evaluated on the basis of its probable physical form and the waste form (i.e., liquid, sludge, or solid). Vapor pressure and Henry's Law constants were considered in identifying volatile compounds in all waste forms. For solid wastes, consideration of the presence of resuspendable, respirable particles in solid wastes was given. Comprehensive chemical inventory data and analyses are provided in a supplemental document, *Data Supporting the 1997 Health Risk Assessment for Hazardous and Mixed Waste Management Facilities at LLNL.*

Air dispersion modeling was used to evaluate the distribution of air emissions of chemicals and radionuclides from the DWTF stack, the Building 612 stack, and the DWTF and Area 612 Yard area sources. For non-radioactive compounds, atmospheric dispersion modeling was performed using the ISC-ST3 model approved by the U.S. Environmental Protection Agency (EPA). Five years of meteorological data from the LLNL meteorological station was used as input to the models. Exposures to actual receptors were modeled at 56 discrete locations, and exposures to hypothetical receptors were modeled at 441 locations. This modeling provided information on the relative concentrations of chemicals at any receptor location. Exposure scenarios were defined for categories of residential, adult-worker offsite/onsite, and youngsters at a child daycare center. Exposures to chemical concentrations in air, soil, and homegrown produce were evaluated for inhalation, ingestion, and absorption (?) pathways. Potential cancer risks and non-cancer risks were calculated for the receptors of interest, based largely on CAL/EPA's *Preliminary Endangerment Assessment (PEA) Guidance Manual* and *Air Toxics "Hot Spots" Program Risk Assessment Guidelines*.

The EPA-approved CAP88-PC model was used to evaluate air dispersion, exposure and dose for radionuclides. Recent meteorological data were used in the simulations. Previous NESHAPs compliance information developed at LLNL for treatment units and operations currently in existence was utilized for emission estimates. Dose was estimated for the hypothetical maximally exposed resident. Risk was estimated by applying the International Commission on Radiological Protection risk factor of 0.05 per Sievert.

In all cases, risk and hazard were evaluated at the maximum anticipated operating levels, so that the risk and hazard estimates represent upper-bound values. The risk assessment found that the cancer risk to the maximum exposed individual (MEI) at a real residential location is 5 E-07, and the cancer risk to the hypothetical residential MEI is 7 E-07, both of which are acceptable risk levels from a regulatory perspective. Similarly, the non-cancer risks to both the real and hypothetical MEIs, expressed as "hazard quotient" were at acceptable levels. The radiological cancer *mortality* risk to the hypothetical residential MEI was 6 E-07, which is also an acceptable risk level.

On the basis of the analyses performed, the risk and the hazard due to the operation of the HWM Division facilities, even at maximum, permitted throughput conditions, are expected to be below levels considered acceptable in the regulatory literature.

Section I. Introduction

SECTION I.   INTRODUCTION

I.1 Purpose and Description

Lawrence Livermore National Laboratory (LLNL) is a U.S. Department of Energy (DOE) facility, located in Livermore, California. It is operated by the University of California (UC) and DOE and serves as a national resource of scientific, technical, and engineering capability. Laboratory activities are focused on national security, energy, the environment, biomedicine, economic competitiveness, and science and mathematics education. LLNL comprises two sites: the main Livermore site (Main Site) and Site 300. Main Site occupies an area of 1.27 mi^2 (3.28 km^2) on the eastern edge of Livermore. Site 300, LLNL's experimental testing site, is located 13 mi (24 km) to the east in the Altamont Hills and occupies an area of 11.7 mi^2 (30.3 km^2) (**Figure I-1**).

LLNL has previously applied for a Hazardous Waste Storage and Treatment Permit for its hazardous waste management facilities at the Main Site in Livermore, CA. The facilities are presently operated under interim status pursuant to the Resource Conservation and Recovery Act (RCRA). The facilities are operated by LLNL's Hazardous Waste Management (HWM) Division in the Environmental Protection Department (EPD). Because HWM Division operates Miscellaneous Treatment Units, as defined by Title 22 of the California Code of Regulations (CCR), Article 66264.600, a health risk assessment is required as part of the RCRA permit application. A health risk assessment was conducted for those HWM Division operations in 1995, pursuant to 22 CCR 66264.601(c). LLNL included all of HWM Division's then existing Main Site operations in the 1995 Health Risk Assessment (HRA), entitled *Health Risk Assessment for Hazardous and Mixed Waste Management Units at LLNL* (McDowell-Boyer *et al.*, 1995).

Subsequent to the publication and distribution of the 1995 HRA, it was determined that the RCRA Part B Permit Application should address the configuration that will exist when the proposed Decontamination and Waste Treatment Facility (DWTF) is operational. The DWTF will treat the same waste streams that are treated in the existing HWM facilities; however, the DWTF will have improved air emissions control equipment and will treat some additional, new waste streams. DOE has assessed the environmental impacts associated with the construction and operation of the DWTF in an Environmental Assessment (DOE/EA-1150). Based on this assessment, DOE issued a finding of no significant impact on June 12, 1996. This 1997 Health Risk Assessment (HRA) has been prepared in support of the revised permit application, and the scope includes the configuration of HWM facilities corresponding to the full operation of DWTF. Specifically, this HRA addresses those facilities that can produce atmospheric emissions and which have potential health effects. The revised RCRA Part B permit application, dated June 28, 1996, includes detailed descriptions of the waste generated at LLNL and the existing waste management units (LLNL, 1996).

I.1.1   Facility Status

As described in the revised Part B permit application, LLNL operates three HWM facilities at its Main Site. These are the Area 612 Facility, the DWTF Complex, and the Building 280 Facility. (The DWTF Complex is a proposed facility, for which Title II design work has been completed.) The Area 612 Facility and the DWTF Complex contain treatment and storage units for hazardous and mixed wastes; the Building 280 Facility is a separate container storage area for hazardous and mixed waste. The Area 514 Yard facilities, which were addressed in the 1995 HRA (McDowell-Boyer *et al.,* 1995), will be functionally transferred to the DWTF Complex.

Hazardous and mixed waste operations at the HWM facilities include the safe and proper handling, storage, treatment, packaging, and disposition of hazardous and mixed waste. Depending on type, the waste may be chemically or physically treated and/or reclaimed. Typical on-site treatment methods include neutralization, flocculation, reduction, oxidation, precipitation, separation, filtration, solidification, size reduction, crushing, compaction, shredding, adsorption, blending, bulking, centrifugation, and evaporation. Wastes are stored in appropriate units on site until shipped off site for treatment and/or disposal

I.1.2   Methodology

This 1997 HRA was prepared in accordance with procedures and guidelines set forth by the State Department of Toxic Substances Control (DTSC) and the Bay Area Air Quality Management District (BAAQMD). It addresses the risk associated with both the hazardous and radioactive properties of chemicals handled at HWM units at LLNL's Main Site. By following these procedures, the 1997 HRA presents a health-conservative analysis of a hypothetical Maximally Exposed Individual (MEI) potentially receiving a reasonable maximum exposure.

Potential carcinogenic risk and noncarcinogenic hazard resulting from the emission of the waste chemicals of concern were characterized largely based on *Preliminary Endangerment Assessment (PEA) Guidance Manual* by the California Environmental Protection Agency, Department of Toxic Substances Control (CAL/EPA/DTSC, 1994); *Air Toxics "Hot Spots" Program Risk Assessment Guidelines* by the California Air Pollution Control Officers Association (CAPCOA, 1993); *Memorandum—California Cancer Potency Factors: Update* and *Air Toxics "Hot Spots" Program Risk Assessment Guidelines* by CAL/EPA/Office of Environmental Health Hazard Assessment (OEHHA)(CAL/EPA/OEHHA, 1994a and 1994b). The contribution to carcinogenic risk from emissions of radionuclides to air was based on National Emissions Standards for Hazardous Air Pollutants (NESHAPs) dose calculations required by federal regulation. In all cases, risk and hazard were evaluated at the maximum anticipated operating levels, so that the risk and hazard estimates represented upper-bound values. The contribution to risk from emissions of radionuclides to air was obtained by multiplying the NESHAPs-calculated dose by the International Commission on Radiological Protection (ICRP) risk factor of 0.05 (lifetime excess cancer mortality risk) per Sievert (ICRP, 1979, 1980, and 1991).

This 1997 HRA was developed using modeling of throughput capacities for the LLNL hazardous waste management units that reflect maximum annual quantities. In actual operations, yearly

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throughputs have been less than these maximum annual quantities. The HRA, therefore, evaluates assumed volatile emissions from hazardous waste management units in excess of historical processing rate emissions. The ability to model the HRA with throughputs greater than the historical processing rates allows LLNL to estimate the potential risk resulting from increasing the treatment volumes to permitted maximums. If the health risk assessment were based on actual historical processing rates, the resulting estimate of risk would be lower than the risks presented in this 1997 HRA. Not all form codes that are described in the Part B application were found in the source term evaluation (LLNL, 1996). Because LLNL is a research and development facility, there is potential for the specific chemicals, mass distributions, and applicable form codes to vary over time; and new wastes may be received in the future. Because of the conservative approaches used in the risk assessment methodology, the maximum risk estimates expressed in the 1997 HRA are expected to bound the future facility risk, with a high degree of confidence.

In summary, this 1997 HRA found that the risk and the hazard due to the continued operation of the existing HWM facilities, even at maximum throughput conditions, would be below levels of concern described in the regulatory literature. The estimate of risk presented in this 1997 HRA is expressed in terms of the risk to human populations. In addition, a qualitative assessment of the potential risks to ecological resources is included in **Supplement D**.

I.2 Organization of the Health Risk Assessment

Section II of this HRA provides a general description of the Main Site's hazardous waste management facilities that have the potential to contribute to risk, as they will exist when the DWTF is operational. For each waste management unit is described in terms of its potential as an emission source and whether it is addressed in this 1997 HRA. **Section III** discusses the development of the lists and quantities of chemicals that could potentially be emitted from operations and explains how those chemicals were screened to determine which compounds should be the subject of the health risk assessment. **Section IV** provides a discussion of the meteorological data, the air dispersion computer modeling for chemicals, and the selection of maximally exposed individuals (MEI) and other receptors. Subsequent sections deal with exposure pathway screening (**Section V**); dose, risk, hazard, and Recommended Exposure Limit (REL), and maximum exposure pathways (**Section VI**); risk, hazard quotient, and REL Hazard Index for MEI Receptors (**Section VII**); and radionuclide atmospheric modeling, dose, and risk (**Section VIII**). The summary of the results in terms of conservatisms and uncertainties is also presented in **Section IX**. Supplemental information in **Volume 1** of this HRA includes **Supplement A,** "Form Codes and Treatment Process Definitions"; **Supplement B**, "Dispersion Model Input Data and Sample of Meteorological Data"; **Supplement C**, "Natural and Man-Made Radiation; and **Supplement D**, "Assessment of Potential Risks to Ecological Resources." **Volume 2** contains **Appendix A** thorough **Appendix M,** which provide the chemical source data upon which this 1997 HRA is based. Additional supporting data regarding waste streams is found in *Health Risk Assessment for Hazardous and Mixed Waste Management Units at LLNL* (McDowell-Boyer *et al.,* 1995) and *Data Supporting the 1995 Health Risk Assessment for Hazardous and Mixed Waste Management Facilities at LLNL* (LLNL, 1995).

I.3 References

California Air Pollution Control Officers Association (CAPCOA). 1993. *CAPCOA Air Toxics "Hot Spots" Program, Revised 1992 Risk Assessment Guidelines.* Toxics Committee of the California Air Pollution Control Officers Association (CAPCOA), in consultation with the Air Toxicology Unit, Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment (OEHHA), and the Special Projects Section, Toxic Air Contaminant Identification Branch, Air Resources Board, Sacramento, CA, October.

California Code of Regulations (CCR). 1995. Title 22, Chapter 14, *Standards for Owners and Operators of Hazardous Waste Transfer, Treatment, Storage, and Disposal Facilities.* Health and Welfare Agency, Sacramento, CA (22 CCR 66264).

California Environmental Protection Program, Department of Toxic Substances Control (CAL/EPA/DTSC). 1994. *Preliminary Endangerment Assessment (PEA) Guidance Manual.* State of California Environmental Protection Agency, Department of Toxic Substances Control, Sacramento, CA, January.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1994a. *Memorandum—California Cancer Potency Factors: Update.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Standards and Criteria Work Group, Sacramento, November (update of the compilation of cancer potency factors issued originally in June 1992; the majority of which have undergone peer review and in many cases rigorous regulatory review).

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1994b. *Air Toxics "Hot Spots "Program Risk Assessment Guidelines: Part 1, Evaluation of Acute Non-Cancer Health Effects, Draft for Public Comment.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, December.

International Commission on Radiological Protection (ICRP). 1979. *Recommendations of the International Commission on Radiological Protection.* Publication 26. Pergamon Press, New York, NY.

International Commission on Radiological Protection (ICRP). 1980. *Limits for Intakes of Radionuclides by Workers.* Publication 30. Pergamon Press, New York, NY.

International Commission on Radiological Protection (ICRP). 1991. *1990 Recommendations of the International Commission on Radiological Protection, Publication 60.* Volume 21, No. 1-3. Pergamon Press, New York, NY.

Lawrence Livermore National Laboratory. 1995. *Data Supporting the 1995 Health Risk Assessment for Hazardous and Mixed Waste Management Facilities at LLNL.* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-AR-122091.

Lawrence Livermore National Laboratory (LLNL). 1996. *Resource Conservation and Recovery Act Part B Permit Application, Hazardous Waste Treatment and Storage Facilities*. Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory. *Environmental Assessment* (DOE/EA-1150) Lawrence Livermore National Laboratory, Livermore, CA

McDowell-Boyer, L.; J. Daniels; G. Gallegos; F. Gouveia; and L. Hall. 1995. *Health Risk Assessment for Hazardous and Mixed Waste Management Units at Lawrence Livermore National Laboratory, 1995.* (1995 Health Risk Assessment [HRA]). Lawrence Livermore National Laboratory, Livermore, CA, UCRL-AR-119482.

I.4 Acronyms

BAAQMD	Bay Area Air Quality Management District
CAL/EPA	California Environmental Protection Agency
CAPCOA	California Air Pollution Control Officers Association
CCR	California Code of Regulations
DOE	U.S. Department of Energy
DTSC	Department of Toxic Substances Control
EPD	Environmental Protection Department
HRA	Health Risk Assessment
HWM	Hazardous Waste Management
ICRP	International Commission on Radiological Protection
LLNL	Lawrence Livermore National Laboratory
MEI	Maximally Exposed Individual
NESHAPS	National Emission Standards for Hazardous Air Pollutants
OEHHA	Office of Environmental Health Hazard Assessment
PEA	Preliminary Endangerment Assessment

RCRA   Resource Conservation and Recovery Act

UC   University of California
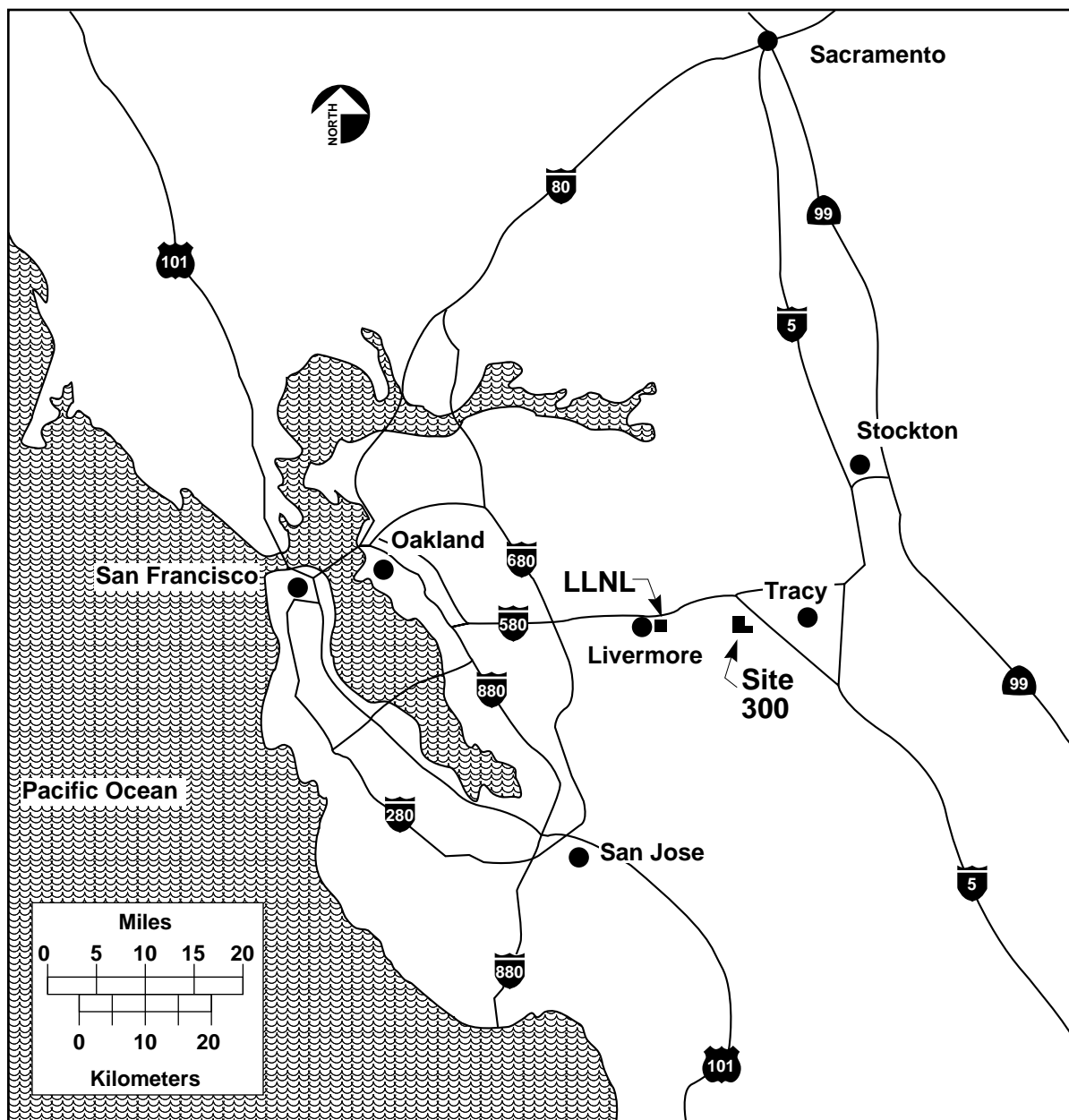
Figure I-1. Regional site of Lawrence Livermore National Laboratory.

Section II.

Facility Design and Operations

SECTION II. FACILITY DESIGN AND OPERATIONS

II.1   Hazardous Waste Management Overview

Hazardous and mixed wastes generated at the Lawrence Livermore National Laboratory (LLNL) Main Site are managed by the Hazardous Waste Management (HWM) Division in accordance with state and federal waste regulations. The hazardous waste management operations consist of several buildings, structures, and equipment that are grouped into the following four storage/treatment units:

- Area 612 Container Storage/Treatment Unit Group

- Building 280 Container Storage Unit

- Building 693 Container Storage Unit Group

- Building 695 Storage/Treatment Unit Group.

Figure II-1 identifies the locations of these storage and treatment units. **Figure II-2** to **Figure II-5** provide general arrangement sketches for each of the above facilities. In general, the Area 612 facilities serve as the primary locations for receiving, storing, processing, decontaminating, size reducing, and packaging solid hazardous waste for off-site shipment. Area 612 is also designed to store liquid and gaseous wastes. Building 280 will be used to store high-curie mixed waste that requires radiation shielding to protect workers. Building 693 will be used to store waste, including flammable waste and waste that is classified for national security. Building 695 will house process equipment to treat liquid, reactive, and debris waste in addition to providing storage capacity for these types of wastes. Gases and other nonroutinely generated, small-quantity waste will also be treated in Building 695.

The Building 280 Storage Unit and the Building 693 Storage Unit are not considered emission sources in this risk assessment because the containers are not opened except for sampling activities while they are stored in the units. The Building 419 Facility includes inactive treatment units that are currently undergoing regulatory closure. This nonoperating unit is not considered an emission source in this risk assessment.

Table II-1 lists all of the storage units and treatment systems included in the June 28, 1997, Part B Permit Application for the LLNL Main Site (LLNL, 1996) that are associated with these facilities. The categories of waste that will be managed in each storage unit and treatment system are identified in this table. Approval to manage those wastes as listed in **Table II-1** is contingent on permit issuance from the California Department of Toxic Substances Control (DTSC). The form codes listed in this table are defined in **Supplement A**. The potential for emissions from each waste management area was evaluated. The evaluation considered the waste managed, the type of operation, and the pollution control equipment provided. The last column of **Table II-1** identifies whether or not the potential emission is considered to be

significant and is, therefore, included in the detailed risk assessment calculations. The rationale for excluding specific waste management areas is provided in this Section.

The interrelationships between these facilities in the overall management of wastes at LLNL is presented in **Figure II-6**. The waste management process consists of:

- Generation and characterization

- Acceptance, staging, and bulking

- Storage

- On-site treatment

- Packaging for off-site shipment.

No waste disposal occurs at the LLNL Main Site. All wastes are eventually shipped off site for recycling, treatment, and/or disposal at a permitted facility or discharged to the sanitary sewer. Each of the above phases in the waste management process are described in the following sections.

II.2 Hazardous Waste Generation and Characterization

Hazardous wastes generated at LLNL range from common household items, such as fluorescent light bulbs, batteries, and paint, to research or industrial operations waste, such as solvents, metals, cyanides, organic chemicals, and pesticides. LLNL personnel are engaged in many diverse activities, and the nature of LLNL research work produces waste with significant variations in form and composition. Consequently, the waste streams generated at LLNL display a range of chemical and physical properties. Mixed wastes, which contain both a hazardous waste component regulated under Resource Conservation and Recovery Act (RCRA) and a radioactive component regulated under the Atomic Energy Act (AEA), are also generated. **Section III**, Source Term Assessment, describes the waste compositions and the manner in which waste stream profiles were developed for this risk assessment.

Waste is typically accumulated in containers or retention tanks at or near the point of generation. The filling of the accumulation containers typically produces negligible emissions because the containers are kept closed when they are not actively being used, only small quantities of waste are typically added to the container, and filling techniques that minimize emissions are used. Moreover, generator accumulation activities are not required to be permitted and are, therefore, not included in the scope of the risk assessment.

Each waste generator, with the assistance of HWM staff, is responsible for identifying, characterizing, and labeling each waste stream. The waste generator is responsible for identifying the chemical constituents and physical characteristics of a waste, based on process knowledge, reference to published sources, or determination by chemical analyses. All information, including the request for any necessary or required chemical analysis needed to adequately treat and/or ship the waste off-site, is provided by the generator. The waste generator

is also responsible for segregating and packaging the waste so that it can be safely transported and stored. Waste is segregated into separate containers according to compatibility and opportunities for recycling. The waste name, identifying constituents, characteristics, and any radionuclides in the waste in each container are recorded on a waste label attached to that container.

Some waste may be transferred directly from the point of generation directly to a HWM facility. However, other containerized wastes are transferred from the point of generation to an assigned Waste Accumulation Area (WAA) once the container has been filled or the accumulation time limit has been reached. Only wastes that have been properly segregated, identified, labeled, packaged, and closed may be stored in a WAA. Waste can be stored at the WAA for up to 90 days from the last date of accumulation at the point of generation. Prior to the expiration of the 90-day time period, the accumulated waste is transferred to the suitable HWM facility receiving area. Some waste may be shipped directly from a WAA to a permitted off-site facility without first going through an HWM facility.

In lieu of using containers, aqueous waste waters may be accumulated at the point of generation in fixed retention tanks for up to 90 days. Aqueous waste that does not meet sewer discharge limits is transferred to the appropriate HWM facility (normally Building 695) using portable tanks or tanker trucks. As with containers from WAAs, aqueous waste may be shipped directly off-site from the point of generation.

II.3   Waste Acceptance

The HWM Division is responsible for managing hazardous wastes from the time that they are picked up from the WAAs until their final disposition (e.g., sewer discharge or off-site shipment). The waste generator completes a Waste Disposal Requisition (WDR) to initiate the transfer of waste from the generator to HWM Division. The WDR contains the following applicable information: hazardous properties, chemical and physical description, predominant hazardous constituents, accumulation start dates, container size, radiation measurements at the container surface and at 1 meter, waste minimization activities, Waste Source Code, and quantity. The WDR information is entered into a database management system that is maintained by the HWM Division for recordkeeping and retrieval. Each WDR is uniquely numbered to facilitate tracking through the computerized database. Subsequent management and treatment information is appended to the database to provide a complete disposition record of the waste stream.

Wastes are not transported to a HWM facility until the waste is adequately characterized to allow for safe receipt, handling, transport, and storage and until the waste is assigned a form code. Wastes are typically delivered to the receiving areas at either Area 612 or Decontamination and Waste Treatment Facility (DWTF); however, some wastes may be directly received at any of the other HWM facilities for storage.

When the waste is received, an abbreviated analysis, referred to as a "fingerprint analysis," is conducted on a representative sample of waste containers, prior to acceptance by HWM, to verify that the contents of the waste containers match the characteristics described on the approved

WDR. In accordance with HWM's waste analysis plan, approximately 10 percent of the total number of WDRs are selected for verification screening by fingerprint analysis. Because the fingerprint analysis is not intended to characterize the waste, visual observation (i.e., color, phase separation) and indicator parameters (i.e., pH, weight, specific gravity, flash point, halogen content, cyanide content, percent water, gross radioactivity) are typically used to confirm the waste generator's characterization. If there is an inconsistency between the WDR and the fingerprint analysis, HWM Division may also request additional waste sampling and detailed analyses to verify the characterization information provided by the generator.

Waste must be approved for receipt by HWM chemists prior to its acceptance to an HWM facility. Wastes considered incompatible with "permitted" operations are not allowed in any HWM facility. Such wastes may be repackaged and shipped directly off site to a permitted facility. Under some circumstances, wastes may be staged at a HWM facility under "HOLD" status while analytical results are pending. As part of the process, all items that are sampled for verification are placed on HOLD so that they cannot be shipped before the verification screening is completed. Only waste that has been characterized adequately for safe handling and proper segregation, using generator knowledge, will be stored while analysis results are pending.

If the waste stream is not acceptable (i.e., the analytical results do not confirm the waste characterization), a verification failure form is filled out. Appropriate forms, requisitions, and any pertinent information are forwarded to HWM Division for resolution. Once the discrepancy is resolved, a waste container discrepancy form is filled out which the generator or designee may be required to acknowledge the discrepancy by signing the completed form. The paperwork is then returned to HWM Division to be reviewed and approved by an HWM Division chemist, to update the database information, and to release the waste item from its HOLD status.

Once the waste is accepted, HWM Division personnel determine whether the waste is appropriate for on-site treatment, storage, or off-site disposition.

II.4   Waste Storage Areas

Table II-2 provides a list of the container storage units and their respective storage capacities within HWM facilities**.** Those capacities listed represent the amount requested by LLNL in the June 1996 Part B Application and is subject to approval by DTSC. Waste containers are kept closed in storage except when wastes are added or removed (as in sampling, transferring, bulking, repackaging, or lab-packing operations). Bungs are tightened and rings are bolted; can lids are shut; valves on tank trailers and portable tanks are kept shut; and boxes are crimped, clamped, stapled, or nailed shut. Portable tank and truck tanker lids/access ways are screwed tight or clamped down. Also, quick disconnects on tank trailers and portable tanks are capped when not in use. Based on the above management practices, waste container storage units are not considered to be a source of emissions for this risk assessment.

II.4.1 Building 280 Container Storage Unit

The Building 280 Container Storage Unit will be a facility located in the northwest quadrant of the LLNL Main Site as shown in **Figure II-3**. The Building 280 Facility will contain the

Building 280 Container Storage Unit that will store hazardous wastes regulated by RCRA and the DTSC as well as RCRA-regulated mixed waste. The container storage capacity (design capacity) of this unit is 135,700 gal (672 yd^3). This unit stores only solid waste in containers that are up to 250 ft^3 in volume. Ignitable, toxic, reactive, and corrosive wastes are grouped by compatibility and segregated accordingly. Wastes stored in the Building 280 Container Unit were previously characterized before storage, and sampling activities would be very infrequent at this unit. Therefore, the Building 280 Container Storage Unit is not considered to be a source for this risk assessment.

II.4.2 Building 693 Container Storage Unit

The Building 693 Container Storage Unit Group, located in the northeast quadrant of the LLNL Main Site as shown in **Figure II-1**, will be used to store RCRA- and DTSC-regulated hazardous and mixed waste (including U.S. Department of Energy [DOE] classified mixed waste) as well as Toxic Substance Control Act- (TSCA-) regulated waste and transuranic waste. The Building 693 Container Storage Unit Group consists of the following storage zones:

- Building 693 Container Storage Cells (four cells)

- Building 693 Annex—Classified Waste Storage

- Building 693 Yard—Freezer Storage

- Building 693 Yard—Roll-off Bin Storage.

This unit group stores solid, liquid, and gaseous wastes. Liquid waste is stored in containers ranging in size from less than 1 gal to 330 gal; solid waste (crushed empty drums and encapsulated solid waste) is stored in containers up to 40 yd^3; and gaseous waste is stored in cylinders that are overpacked in containers up to 250 ft^3. Ignitable, reactive, toxic, and corrosive wastes are grouped by compatibility and appropriately segregated in the four cells within Building 693 and the Building 693 Yard—Freezer Storage. The Building 693 Container Storage Unit Group is illustrated in **Figure II-4**.

Wastes stored in the Building 693 Container Storage Unit Group were previously characterized before storage. Sampling, and other miscellaneous handling operations would occur very infrequently. Therefore, this unit group is not considered to be a source for this risk assessment.

II.5   Treatment and Process System Descriptions

On-site treatment is typically conducted to:

- Allow the controlled discharge of treated aqueous waste waters to the sanitary sewer

- Comply with Land Disposal Restriction (LDR) treatment standards and waste acceptance criteria for off-site disposal facilities

- Separate radiological waste characteristics and hazardous waste characteristics.

- Pretreat waste when alternative commercial treatment or disposal options are not readily available.

Treatment activities are not performed in any unit unless prior approval has been granted by qualified HWM Division scientists, engineers, or facility supervisors. Standard operating procedures (SOPs) are developed by HWM Division when necessary to ensure that each treatment operation is conducted safely. Experienced technical experts who are knowledgeable with the process chemistry hazards, process controls, and treatment equipment limitations assist with preparing the SOPs. Past operational experience and lessons learned are also considered. All SOPs are thoroughly reviewed by HWM Division management and staff prior to being approved for use.

The waste treatment train selected for each waste stream is based on the waste characteristics, size of the waste batch, results of bench-scale testing (including process optimization experiments, treatability studies, and treatment "recipe" formulation), and previous operational experience with similar wastes. Treatment processes may be linked together for treating wastes with multiple characteristics.

Table II-3 lists the on-site treatment processes that may be used to achieve the above treatment goals. **Supplement A** provides a brief definition for each treatment process that is proposed to be conducted at the LLNL Main Site. The treatment systems that will be installed in Area 612 and Building 695 are listed in **Table II-4**. This table also identifies the types of waste that will be managed in each treatment system. The following subsections provide a brief description of the equipment operations and potential emission sources.

II.5.1 Area 612 Container Storage/Treatment Unit Group

The Area 612 Facility is located in the southeast quadrant of the LLNL Main Site (see **Figure II-1**). A layout of the Area 612 Facility is shown in **Figure II-2**. The facility consists of a fenced area approximately 243 ft (74 m) wide by 547 ft (167 m) long. The following units are exclusively used to store containers, tank trailers, or portable tanks: the Building 612 Container Storage Unit, Building 614, Building 625 Container Storage Unit, Area 612 Portable Tank Storage Unit, Area 612 Tank Trailer Storage Unit, Area 612-4 Receiving, Segregation, and Container Storage Unit, Area 612-2 Container Storage Unit, Area 612-5 Container Storage Units, and 612-1 Container Storage Units. The storage units consist of either buildings, tents, or bermed areas where drums, smaller containers, or portable tanks are stored pending on-site treatment and eventual off-site disposition.

The Area 612 Facility is primarily used to store and process solid waste, but limited liquid waste storage and bulking will also be conducted. The majority of wastes handled arrive in a sealed container and are typically shipped off site without ever being opened. Some waste containers are opened for verification screening and quality assurance.

The waste handling and treatment processes conducted at the Area 612 Facility include crushing empty drums; decontaminating (e.g., vacuuming and wiping) and size reducing contaminated equipment and debris; and bulking and packaging (including preparing lab packs) waste for off-site shipment. These waste handling and treatment systems include the Drum/Container Crushing Units, the Size Reduction Unit, and the Lab Packing/Packaging Container Storage Unit. These three systems are located in Building 612 as shown in **Figure II-7**. Wastes are also transferred and combined at the Area 612 Facility. These transfer operations are considered an emission source in this risk assessment and are described in **Section II-6**. Decontamination and size reduction activities are considered to be emission sources in this risk assessment. These processes are described in **Section II.5.1.2**.

II.5.1.1   Drum/Container Crushing Units

Containers and drums that previously held hazardous wastes are managed in accordance with the California Code of Regulations (CCR), Title 22, Article 66261.7 (22 CCR 66261.7). These containers and drums are emptied and washed, as required, to conform with these regulatory requirements. After emptying and washing, nonreusable containers and drums are compacted in a drum crusher to facilitate packaging and to reduce the volume of waste shipped off site for disposal or placed into long-term, on-site storage.

There is a drum/container crushing unit currently located in the western portion of Building 612 (Room 100). A second identical unit will be added at a later date. The drum crushers are used intermittently to compact empty and dry drums and containers that have a capacity less than 55 gal. During compaction, a blower pulls air from the compaction chamber and through a high-efficiency particulate air (HEPA) filter to remove any solid particulates. Because the crushing process is strictly a mechanical operation and no chemical processing occurs, hazardous constituents (including volatile organic compounds) are not expected to be emitted. As such, these crushing units are not considered to be an emission source in this risk assessment.

II.5.1.2   Size Reduction Unit

The Size Reduction Unit, also referred to as a repackaging and decontamination booth, is located in the central portion of Building 612 (Room 100). This unit consists of a stainless steel walk-in booth with a HEPA-filtered ventilation system. A personnel airlock (with separate ventilation system) is attached to the north side of the booth, and a loading platform is located at the east end to support the size reduction activities. The walk-in booth is designed to prevent the release of airborne particles and liquids when decontaminating and dismantling contaminated equipment, thus protecting workers and the environment. The booth may also be used for lab packing, inspecting, assaying, sampling, bulking, and overpacking waste in containers to comply with the certification requirements for off-site disposal facilities.

The waste typically sent to the booth are large pieces of equipment (such as glove boxes, pumps, machining tools, and tanks) that have fixed or removable contaminants that exceed safe handling and/or disposal limits. This equipment may need to be decontaminated, size reduced, and/or dismantled to remove residual contaminants for disposal, maintenance, or reuse.

Waste decontamination techniques include, but are not limited to, wiping with cloths, vacuuming, water/surfactant washing, abrasive blasting, and rinsing. The cloths may be treated with special chemicals to facilitate removal of contaminants. Aqueous-based detergents will be used to wash equipment surfaces. The washing equipment operates at high pressures and can be used to heat the decontamination solutions. Abrasive blasting is used to physically remove contaminated paints, rust, and other surfaces. A slurry consisting of water and oxide grit is the abrasive medium that is typically used.

Equipment is dismantled and size reduced using a variety of hand-held tools, including but not limited to drills, saws, chisels, wrenches, sockets, ratchets, hammers, and screwdrivers. No torches or open flames are used for cutting. The power tools are either pneumatically or electrically driven. These tools are dedicated to the booth. Surface radiation measurements may be collected as the piece of equipment is dismantled. If required, the equipment is periodically decontaminated to remove contaminants that are detected.

Following decontamination, the dismantled parts are sorted and segregated. Noncontaminated materials (e.g., nonradioactive and nonhazardous) are reused/recycled, sold as scrap, or packaged for off-site disposal at a Subtitle D solid waste landfill. Nonhazardous, low-level radioactive wastes are shipped off site to an appropriate radioactive waste disposal facility. Materials with non-removable hazardous waste contaminants would be transferred to an off-site RCRA-permitted facility. Mixed wastes that cannot be decontaminated may be packaged for long-term, on-site storage if off-site disposal capacity is not available. Some of the size reduced waste may be solidified to further immobilize residual contaminants. Other wastes may be further size reduced in the shredder/chopper for subsequent treatment in the debris washer or solidification system. Washwater and the abrasive slurry are recycled to reclaim the abrasive media.

Wastes designated for treatment in this unit are contaminated with various radionuclides, volatile organic compounds, and mercury and other metals. The closed booth will be vented to create a negative pressure, and the air suction/venting system will be equipped with a series of HEPA filters, which will significantly reduce particulate emissions; no carbon adsorption abatement is planned. This unit is considered an emission source of small-diameter particulates and volatile compounds.

II.5.1.3 Lab Packing/Packaging Container Storage Unit

LLNL typically generates small quantities (less than 5 gal) of many different types of used and unused laboratory chemicals. These smaller containers of liquid or solid hazardous waste may be consolidated into a single, larger lab pack to facilitate shipment to an off-site facility. The lab packs conform with the U.S. Department of Transportation (DOT) requirements specified in the Code of Federal Regulations (CFR), Title 49, Subchapter C, "Hazardous Materials Regulations." Lab packs that are shipped to a permitted landfill for disposal also comply with the requirements of 22 CCR 66264.316, 66268.32(m) and 66268.42(c).

In general, lab packing involves preparing small containers of compatible chemicals for off-site disposition by arranging them in adsorbent material inside a larger overpack container. Because

the lab packed items are not normally opened but are overpacked, the lab packing operation is not considered to be a source of emissions for this risk assessment.

II.5.2   Building 695 Storage/Treatment Unit Group

Building 695, also called the Liquid Waste Processing Building (LWPB), will be constructed as a component of the DWTF Complex in the northeast quadrant of the LLNL Main Site (see **Figure II-1**). A layout of Building 695 is shown in **Figure II-5**. The building is approximately 123 ft (37 m) wide by 213 ft (65 m) long. The building will contain several storage and processing areas. The following equipment will be installed to treat liquid, solid, and gaseous waste:

- Nine storage/treatment tanks

- Waste blending station

- Cold vapor evaporator

- Centrifuge

- Filtration module

- Shredder/chopper

- Debris washer

- Solidification system

- Gas adsorption system

- Uranium bleaching

- Pressure reactor

- Water reactor

- Amalgamation reactor.

Descriptions of the equipment operations and expected emissions are presented in **Section II.5.2.1** to **Section II.5.2.14**. The above equipment was specifically selected to treat the waste streams that are expected to be generated. However, some waste may have unique characteristics that preclude treatment by the above equipment and shipment to an off-site treatment, storage, and disposal (TSD) facility. Because these unique wastes are infrequently generated, installing dedicated equipment is neither practical nor cost effective. Bench-scale treatment processes will be developed on a case-by-case basis and conducted either in the Small-Scale Treatment Laboratory (SSTL) or the reactive waste processing (RWP) area. Additional details regarding small-scale treatment processes is provided in **Section II.5.2.14**.

Localized air abatement systems will be provided for a majority of the treatment systems to remove hazardous constituents from the process off-gases. The treated process off-gases will be combined with the building ventilation for final HEPA filtering and monitoring prior to being discharge to the atmosphere. **Figure II-8** provides a process flow diagram for the Building 695 off-gas treatment system.

II.5.2.1 DWTF Tank Farm

The DWTF tank farm will consist of nine 5,000-gal (18,925-L) tanks and ancillary equipment, such as piping, transfer pumps, agitators, and instrumentation. The vertical, conical-bottom, cylindrical tanks will be equipped with high-level alarms and high-level interlocks to prevent overfilling. Each tank is designed to have a working capacity of approximately 4,000 gal (15,140 L). The DWTF tank farm will replace the existing, open-top waste water treatment tanks located in Area 514.

The tank farm is designed to store and treat aqueous waste that may contain metals, oils, radionuclides, solvents and other organic compounds. The liquid wastes will arrive at Building 695 in portable tanks and containers. The tanks will also be used as a place for accumulating and bulking small volumes of compatible waste to form larger batches, thus minimizing the number of treatment campaigns required to be performed. The bulking operations will also be used as a form of pretreatment by combining the waste in such a manner that beneficial chemical reactions occur. The characteristics of the waste will be evaluated prior to bulking to prevent undesired and unsafe reactions.

Two parallel transfer lines will run along the western wall of Building 695 between the tank farm and the airlock. The transfer lines will be used to transfer untreated waste (e.g., "dirty" waste) and treated effluent (e.g., "clean" waste) between waste containers, treatment systems, and the tank farm. Four quick-disconnect stations will be strategically located along these transfer lines to facilitate the transfer operations. All quick-disconnect stations will be equipped with isolation valves and located within a secondary containment zone to contain any leakage and spillage. Piping and remotely operated valves will be provided to allow the waste to be transferred into and between any of the nine tanks. Flexible hose and portable pumps will be used to make the final connection between the quick-disconnect stations, waste containers, portable tanks, or treatment equipment.

Chemical reagents can be added directly to the tanks to allow a variety of chemical treatment processes (i.e., neutralization, oxidation/reduction, precipitation, chlorination, cyanide destruction, degradation, detoxification, and liquid ion exchange). The tanks also are used for physical separations by decanting, settling, and flotation. The bulking, mixing, and treatment of aqueous wastes in the tank farm are the primary source of emissions considered in this risk assessment.

A single, local off-gas treatment system will be provided for the DWTF tank farm. The abatement equipment will consist of a HEPA filter, a heater, two carbon adsorption columns, and a variable-speed drive blower. The carbon columns are designed to remove organics that may be present in the off-gas. The carbon adsorption columns will be operated in series; the second

carbon column is used as a redundant back-up to prevent the release of organics when the first column becomes saturated. A photo ionization detector (PID) will be installed between the carbon columns to determine when breakthrough of the first column occurs.

Because the adsorption efficiencies of the carbon beds can be reduced when particulates deposit on the active sites of the carbon, a HEPA filter will be installed upstream of the carbon columns. A heater will be installed to reduce the relative humidity of gases from the tank farm. The heater is sized to prevent condensation that could damage the HEPA filters and to reduce the relative humidity of the gas below 50 percent in order to optimize the absorptive properties of the carbon beds. The blower is designed to maintain a slight negative pressure within the tanks while two hatches are open and three tanks are being filled. Pressure instrumentation and process controls will be provided to automatically maintain negative pressures in the tanks.

After treatment of the waste batch or campaign is completed, the treated waste is sampled and analyzed to determine if the effluent can be discharged to the City of Livermore Water Reclamation Plant (LWRP). Waste effluents that exceed discharge limits will either be subjected to further treatment in the tank farm, transferred to another on-site treatment process (i.e., evaporation, centrifugation, filtration, solidification, etc.) or packaged for off-site shipment. The disposition determination will be made by the HWM Division review chemist or process engineer in accordance with established procedures and permit requirements. LLNL has a number of procedures and engineering controls in place in order to ensure the continuous quality of waste water discharged to the collection system and the LWRP. These control measures are discussed in detail in Appendix B of the *Health Risk Assessment for Hazardous and Mixed Waste Management Units at Lawrence Livermore National Laboratory, 1995* (1995 Health Risk Assessment [HRA]) (McDowell-Boyer *et al.*, 1995). Waste water discharged to the sanitary sewer is not considered a source of emissions for this risk assessment.

II.5.2.2   Waste Blending Station

The waste blending station serves two primary purposes. The first is to combine smaller waste batches in a controlled manner to obtain a homogeneous mixture for subsequent treatment. The blending process is also used to reduce the relative hazards of the unblended wastes and to pretreat the waste by combining the unblended waste in a manner that produces beneficial chemical reactions. The second use is to thoroughly mix waste waters and chemical reagents together to treat a batch of waste water on a semi-continuous basis and in a controlled manner.

A blending/treatment plan will be developed and documented each time blending is proposed. The characteristics of the waste batches will be evaluated to preventing undesired reactions that are extremely exothermic, generate toxic gases that cannot be removed by the air pollution control equipment, or form hard-to-treat byproducts.

The waste blending station has been fabricated for installation in Area 514-1 as an interim status modification and will subsequently be transferred to the Building 695 as existing equipment. The mixing vessel has a capacity of approximately 100 gal (380 L). The mixing vessel has a closed top with sealed inlets and outlets for transferring waste, adding chemical reagents, inserting monitoring instruments, and venting. To allow blending in portable tanks, a lid

assembly that attaches to the main hatch opening of the portable tank is used. The lid assembly has inlets and outlets that are functionally similar to the mixing vessel. The mixing vessel is typically used to blend waste streams that are less than 55 gal (190 L) and the portable blending tank will be used for larger volumes.

The waste blending station will have mixing equipment to provide a homogenous solution. A variable speed, top entering, mixer is permanently mounted in the mixing vessel. Compressed air will normally be used to mix the contents of the portable blending tank. Pump recirculation may also be used as an alternate mixing method. To minimize the possibility of undesired reactions and to dissipate reaction heat, the contents will be well mixed while other wastes or chemical reagents are slowly added in a controlled manner. The pH and temperature will be monitored during blending and mixing operations. Operators will take the appropriate corrective actions (e.g., terminating chemical reagent additions) if a sharp pH or temperature fluctuation is observed.

Both the mixing vessel and lid assembly will be operated under a slight negative pressure to prevent the uncontrolled release of airborne emissions. The off-gases are vented to a gas adsorption system that consists of a scrubber, heater, HEPA filter, and carbon adsorption columns. The design and operation of this system is similar to the one that will be installed for the tank farm. This gas adsorption system will also be used to treat off-gases from the cold vapor evaporator and centrifuge. Emissions from this unit were evaluated as part of the 514 Waste Water Treatment Tank Farm Ancillary Equipment in the 1995 HRA (McDowell-Boyer *et al.*, 1995). Consistent with that approach, emissions from the waste blending station are accounted for in the source term calculations for the DWTF tank farm.

II.5.2.3   Cold Vapor Evaporator

The cold vapor evaporator has been fabricated for installation in Area 514-1 as an interim status modification and will subsequently be transferred to the Building 695 as an existing piece of equipment. The cold vapor evaporator is designed to concentrate dissolved radioactive and hazardous solids by evaporating water from the waste. The goal of the evaporation process is to produce a "clean" condensate that can be discharged to the sanitary sewer. The evaporator selected for the LLNL uses a vacuum and refrigerant system. The evaporator will typically be operated on a batch basis, and the tank farm will normally be used as the source of the waste feed. Waste containers, including portable tanks, may also be used as the source of the waste feed when small batches of waste are to be treated.

The normal operating pressure of the evaporator pot will be approximately 0.3 psia. At this pressure, water evaporates from waste at approximately 65˚F. The normal operating temperature of the evaporator pot will be maintained at approximately 70˚F to ensure that a "clean" condensate is obtained. The above operating settings may need to be varied to accommodate the vapor pressure of the waste feed and in response to changes in ambient conditions. The maximum operating temperature of the evaporator pot is 140˚F. Compounds which also have vapor pressures less than the operating pressure at the operating temperature will also vaporize. Properties, such as boiling point rise, temperature, pressure, and heat transfer, will be evaluated

to predict treatment effectiveness and the composition of the condensate and concentrate waste streams as well as the off-gas.

A mist eliminator is provided at the top of each evaporator pot to remove liquids and other particulates that may be entrained in the off-gas stream (e.g., vaporized water). The vaporized water and other compounds are condensed in the condenser and accumulated in the distillate collection tank. The operating temperature of the condenser will normally be less than 50°F. However, this temperature may fluctuate with ambient temperatures and flow rate of the condensate. The off-gas from the condensers subsequently passes through a low-temperature, refrigerated vapor trap to minimize the carryover of water vapor and volatile organics. The condensate from the vapor trap is also accumulated in the distillate collection tank. Although volatile organic emissions are expected to be minimal, the off-gases from the evaporator system will be vented to the gas adsorption system. Fugitive gaseous emissions from the evaporator are precluded because the pressure in the evaporator is lower than the ambient pressure.

The evaporation process provides "clean" condensate that will be transferred from the distillate collection tank to a receiving waste container, portable tank, or the tank farm. Flexible hoses will be used to provide the necessary connections between the evaporator and the receiving containers or tank farm transfer line. Condensate that meets LLNL internal limits will be discharged to sanitary sewer. The transfer of condensate is not considered to be an emission source because it is "clean."

The concentrate (e.g., evaporator bottoms) consisting of the nonvolatile constituents (e.g., salts and low vapor pressure organic matter), precipitates, and suspended solids will be collected within the evaporator pot. The concentrate will normally be transferred from the evaporator pot to a waste container or portable tank. If required, the concentrate will be subjected to additional on-site treatment (e.g., solidification) prior to being shipped off site. Samples of the concentrate will be collected and analyzed, when required, to characterize the waste and to provide information for a waste management determination and subsequent treatment.

The aqueous wastes handled in the cold vapor evaporator represent a subset of the aqueous waste handled in the DWTF at the tank farm. Consequently, volatile emissions from this unit are accounted for in the evaluation of the DWTF tank farm and are not addressed separately (see **Section II.5.2.9**). This is consistent with the approach taken in the 1995 HRA (McDowell-Boyer *et al.*, 1995).

II.5.2.4   Centrifuge

The purpose of the centrifuge is to selectively separate multi-phasic, immiscible liquids and heterogeneous liquid/solid solutions into several phases based on differences in their respective densities. By attaining separated phases that are more homogeneous than the original waste stream, subsequent treatment operations (e.g., evaporation), if required, will be more effective. One goal of the centrifugation process is to reduce the volume of mixed waste by isolating radioactive and/or hazardous waste constituents into one of the separated phases, thus allowing the other phases to be managed as nonradioactive and/or nonhazardous wastes.

The centrifuge has been fabricated for installation in Area 514-1 as an interim status modification and will subsequently be transferred to the Building 695 as an existing piece of equipment. This centrifuge is designed to separate wastes into three phases: solids, light liquids and heavy liquids. Typically, either a storage tank or a portable tank will be used as the source of the waste feed. Each batch of waste will normally be fed the centrifuge on a continuous campaign basis under full automatic operations. Containers and/or portable tanks will normally be used to hold the separated phases and sludge. Flexible hoses will be used to make the required connections. All gaseous emissions emanating from the centrifuge will be treated by the gas adsorption system. The portion of volatile gases not captured by the adsorption system represents an emission source in this risk assessment (see **Section II.5.2.9**.)

II.5.2.5   Filtration Module

The filtration module is a new piece of equipment that will be installed in Building 695. This module, in conjunction with the evaporator, will replace the filtration functions currently provided by the Dorr-Oliver rotary vacuum filter located in Building 514. Current plans are to modify an existing microfiltration system to expand its filtering capabilities by adding flange connections, by-pass lines, and instrumentation to accommodate a variety of different types of filter and adsorption media. The microfiltration system was originally fabricated to conduct treatability studies in removing small-diameter particulates from surrogate waste waters.

The filtration module will be used most often to remove solid and ionic contaminants (e.g., precipitates, suspended solids, particulates, cations, and anions) from waste water so that the treated filtrate can be discharged to the sanitary sewer. The module is a specialty treatment process that will be able to remove very small-diameter particles and/or specific target contaminants from waste waters. The filtration process may also be used to remove impurities from spent oils, solvents, and coolants to allow them to be reused.

Various types of filter elements can be installed and changed depending on the desired filtration result. Polypropylene cartridge filters rated for 25 microns or smaller will be used to filter out successively smaller particles as the waste water passes through the system. Adsorption cartridges, consisting of activated carbon or clay-anthracite, will be used to adsorb of coolants from waste waters. Membrane diffusion filters will be used to separate oil, chlorosolvents, and insoluble metals from water, soluble hydrocarbons and soluble metals. Cross-flow nanofilters that are designed to concentrate and remove water-soluble hydrocarbons will also be used. Reverse osmosis membrane filters will be used to remove soluble metals and salts.

A feed/mixing vessel is provided to hold the waste water being filtered. The vessel will be equipped with an agitator to ensure that solids do not settle out in the vessel. The feed/mixing vessel will also be equipped with a passive vent that will be fitted with a carbon canister. Other portions of the filtration module (e.g., piping and filter elements) will be a completely closed system. Residual off-gases from this unit constitute an emission source.

II.5.2.6   Shredder/Chopper

The shredder and the chopper will be used to size reduce solid waste for subsequent treatment in the solidification system or the debris washer. The size reduced materials may also be packaged for off-site shipment. The existing shredder installed in Building 513 (Room 1002) will be moved to Building 695. A chopper will be purchased and installed in Building 695 to supplement the size reduction capabilities. Although the manufacturer has not yet been selected, the chopper will be functionally similar to the existing shedder except for having rotating cutters.

Both pieces of equipment use low-speed, high-torque, rotating cutting surfaces to size reduce the debris by ripping, shearing, and tearing actions. The shredder and the chopper will be equipped with different cutting surfaces to accommodate different types of debris. The shredder will be able to process cloth, paper, cardboard, and other fibrous materials. These debris exit the shredder as strips. The feed to the chopper will typically include harder materials, such as thin-gauge metal, wood, glass, and rubber. These debris are sheared into smaller pieces. Wastes with free liquids are prohibited.

A hopper is provided to direct the debris to the cutting surfaces. The hopper lid remains closed during size reduction operations to protect workers from flying debris and to prevent airborne emissions. A blower with a HEPA filter will be provided to capture airborne particulates that may be generated during the size reduction operations. Residual particulate material from this unit and volatile compounds released from solid waste are considered sources of emissions in this risk assessment.

II.5.2.7   Debris Washer

Hazardous debris are required to be treated in accordance with the treatment standards listed in Table 1 of 22 CCR 66268.45. The contaminated debris generated at LLNL may include paper, cloth, personal protective equipment, glass, wood, thin-gage metals, and rubber products. Hazardous debris may also be contaminated with radionuclides.

The debris washer is a new piece of equipment that will be installed in the Building 695 to comply with the above-mentioned regulatory requirements. Currently, commercially available treatment equipment are being evaluated to determine the one best suited for treating LLNL-generated debris. If required, treatability studies will be conducted prior to making a final decision on equipment purchase.

Conceptually, the debris washer will be a liquid extraction process consisting of a wash water feed tank; a washing chamber; a heating/drying element; and associated pumps, pipes, and mixing equipment. At the present time, it is anticipated that the wash solution will either contain an acid or a surfactant. Nitric or sulfuric acid will be used to leach metals and break down heavy organics. Detergents or other surfactants will be used to enhance removal of dirt or organic material. Other types of solvents, including organic solvents, may be used to extract specific target contaminants. However, the risk assessment does not specifically evaluate emissions associated with the potential future use of organic solvents in this unit. Treatment effectiveness, cost, and compatibility will be considered when determining which extraction solution should be

used. The washing chamber will be agitated and/or have spray nozzles to ensure that all debris surfaces uniformly come in contact with the wash solution. The washing solution may also be heated to increase the solubility of the contaminants.

After the washing cycle is completed, the wash water will be pumped from the chamber into a waste container or portable tank. The debris may undergo subsequent washing cycles with the same or another solution, or the debris may be rinsed to remove washing solution residuals. The disposition of the spent wash and rinse waters (i.e., transferred to the tank farm or discharged to the sanitary sewer) will be based on analytical results. The debris will then dried. The two drying options being considered are to install an electrical heating element located within the chamber or to pass heated air through the chamber. It is expected that temperatures up to 300°F can be maintained with either option. Following drying, the treated debris will be removed from the washing chamber and placed into a waste container. Waste that is deemed to not be clean enough for direct disposal (e.g., debris containing excessive radionuclide concentrations) may be sent to the solidification system for immobilization.

The debris washer will be operated under a slight negative pressure to prevent the uncontrolled release of airborne emissions. The off-gases will be vented to a local air pollution abatement system that consists of a scrubber, heater, HEPA filter, carbon adsorption columns, and a constant speed blower. Because the off-gases from the debris washer are expected to contain acid gases or strong oxidizers, scrubbing is required to prevent the discharge of these components and the corrosion of downstream equipment. The scrubber will also remove other soluble compounds from the off-gas. The gases from the scrubber will be dehumidified (e.g., using a mist eliminator and a heater) to ensure that the HEPA filters are not damaged, and the adsorptive properties of the carbon beds are not compromised. Both the treated off-gases and particulate material from the debris washer are considered to be sources of emissions and are evaluated in this risk assessment.

II.5.2.8   Solidification System

The solidification system is an existing piece of equipment that is presently installed in Building 513 and will be transferred to Building 695. The solidification system is a commonly used industrial method to solidify free liquids and to immobilize toxic waste constituents by various chemical reactions (e.g., hydration, cementation). The solidified material must pass the appropriate LDR treatment standards for land disposal. Solidification and recipe formulation may also be conducted in the small-scale treatment laboratory using bench-scale equipment.

The existing solidification system includes a double planetary drum mixer that is used to solidify waste on a batch basis. Both liquid and solid waste will be treated in the solidification system. The wastes will normally be pumped or scooped from portable tanks or containers into a 55-gal drum. The DWTF tank farm may, on occasion, be used as the source of the waste feed. Adequate freeboard will be maintained for adding and mixing solidification agents.

Dry powders will be the primary solidification agent used. The solidification agents include, but are not limited to, Portland cement, gypsum cement, attapulgite clay, sepulite clay, bentonite clay, monomorillonite clay, and quaternary amine silicate clay. Although these solidification

agents are not hazardous, a local hood will be installed above the preparation area to draw the dust away from workers, prevent dispersion of the solidification agents, and help maintain the cleanliness of the solidification area. A local prefilter will be provided at the hood to decrease the maintenance requirements for the general building ventilation system (i.e., change-out of the Building 695 HEPA filters).

Once the solidification agents have been added to the waste, the 55-gal drum is wheeled into position, and the agitators are lower into the waste. The agitators are supported by a hood/mixer assembly that provides a watertight, dust-tight seal with the 55-gal drum to prevent liquid spillage or airborne releases during mixing. Feed ports are provided in the hood to allow waste and solidification agents to be added to the drum after the hood/mixer assembly is lowered into place. However, the solidification agents will normally be added to the drum before the hood/mixer assembly is lowered.

After the batch of waste is thoroughly mixed, the hood/mixer assembly is raised to allow removal of the drum from the skid platform. Any residue that remains on the agitator assembly is knocked and/or scraped off into the drum. When the treatment process is finished, the agitator is cleaned (washed and/or wiped) so that no visible residue remains. Each drum is sealed with a lid to prevent spillage when it is moved to the curing area.

Some of the waste destined for treatment in the solidification unit is contaminated with volatile compounds, which represent a source of emissions. Particulate releases from this unit are also considered in the risk assessment.

II.5.2.9   Gas Adsorption System

The gas adsorption system has been fabricated for installation in Area 514-1 as an air abatement control device for treating off-gases from the waste blending station, evaporator, and centrifuge. In addition to treating off-gases from the treatment equipment identified above, this air pollution control equipment will be used on a nonroutine basis to directly treat compressed hazardous waste gases (see **Section II.5.2.14, Other Nonroutine Small-Scale Treatment Processes**). This treatment system will subsequently be transferred to Building 695 as an existing piece of equipment.

The gas adsorption system consists of a compressed gas opening station, fume scrubber to neutralize acid gases, a mist eliminator, a heater and process air connection for dehumidification, a HEPA filter for particulate removal, a blower, and two carbon columns to adsorb volatile organic compounds. The heater and condensing air connection will be added to the gas adsorption system when it is in Area 514-1 to improve the treatment effectiveness. The gas cylinder opening station will also be added to accommodate the treatment of compressed hazardous waste gases (see **Section II.5.2.14**). The operation of the gas adsorption system is similar to the local off-gas treatment system that will be provided for the DWTF tank farm (see **Section II.5.2.1**).

A common air duct manifold will be used to connect the gas adsorption system to the ventilation ducts for the waste blending station, centrifuge, and cold vapor evaporator. The duct is equipped

with isolation dampers to allow air flow to be adjusted between the treatment equipment as the load dictates. The system is sized so that removal efficiencies are not impacted regardless of the number or combination of treatment units exhausting to the duct.

For purposes of the risk assessment, off-gases from the waste blending station and cold vapor evaporator are accounted for in the evaluation of volatilization losses from the DWTF tank farm; emissions associated with treatment of waste in the centrifuge are addressed separately for that unit (see **Sections II.5.2.2**, **II.5.2.3**, and **II.5.2.4**). Volatile emissions resulting solely from the nonroutine treatment of compressed hazardous waste gases are discussed in **Section II.5.2.14**.

II.5.2.10   Uranium Bleaching Process

The uranium bleaching process is a new treatment system that will be used to convert (oxidize) uranium chips and mill turnings to a stable compound (uranium dioxide) that is amenable for disposal. The uranium bleaching process will take place in the reactive materials cell. Although the exact design for this treatment process has not yet been finalized, the treatment system is being designed to control the rate of reaction, dissipate exothermic heat generation, and manage product off-gases safely.

Because of the inherent fire dangers, uranium chips and mill turnings are typically immersed in oils or machining coolants and stored in containers with a capacity of 55 gal or less. In order to ship this waste stream off site for disposal, the oil and coolants must be removed, and the uranium deactivated through an oxidation process. The treatment process involves draining the immersing fluid from the chips followed by a controlled reaction between the primarily depleted uranium and an oxidant (sodium hypochlorite or hydrogen peroxide). Upon completion of the oxidation reaction, a reducing agent (sodium thiosulfate) is added to form uranium dioxide. The resulting waste product will typically be solidified prior to shipment off site. The oxidation treatment process will take place within a reaction vessel. The uranium waste will be treated in small batches (approximately 80 lb) to further minimize the potential for "run-away" reactions.

The uranium bleaching process is expected to release volatile organic compounds and to generate hydrochloric acid vapors. The ventilation system for the reactive materials cell is designed to direct the off-gases away from operating personnel working inside the cell. A dedicated local off-gas treatment system will be provided and sized to treat the ventilation air. The local system will consist of an acid gas scrubber, heater, prefilter and HEPA filter, blower, and two carbon columns. Hydrogen and oxygen may also be generated during the oxidation reaction and through the decomposition of sodium hypochlorite. Because of these potential fire/explosion hazards, inert nitrogen gas will be used during the oxidation reaction to purge the reaction vessel. The treated off-gases from the uranium bleaching process are considered to be a source of emissions and are evaluated in this risk assessment.

II.5.2.11   Pressure Reactor

The pressure reactor is a piece of bench-scale equipment that is commonly used in the chemical manufacturing industry. HWM Division's pressure reactor is currently being used to conduct treatability studies and is proposed to be permitted to safely treat small batches (approximately

750 mL or less) of waste that requires the maintenance of precise temperature and pressure controls. These reactions include endothermic reactions that require heating to ensure that the desired reaction occurs; extremely exothermic reactions; and other unstable reactions that can generate explosive, high pressures, and/or toxic gases if the reaction rate and/or conditions are not properly controlled.

The pressure reactor is a batch process where the reaction vessel is charged with waste by either removing the vessel head and directly filling the vessel with waste or introducing waste through one of the valved fittings that are mounted on the head of the vessel. After filling the vessel with waste, the vessel head and/or sample valves are sealed. Chemical reagents are introduced into the reaction vessel through a valved fitting at a controlled rate. The reactor is equipped with pressure/temperature instruments, a stirrer, and a heating/cooling coil to monitor and control the reaction.

The reactor may be kept closed or vented. Any off-gases will normally be vented into the building ventilation system either through a glove box or hood. Both the glove boxes and hoods that will be located in the reactive waste processing room and the small-scale treatment laboratory will have a local air abatement control system. The glove boxes will be equipped with a HEPA filter, and the hoods will have an acid scrubber and carbon column in addition to HEPA filtration. If required, a bench-scale off-gas treatment system will be assembled to treat specific reaction products. Gaseous emissions and particulate releases from the pressure reactor may occur during direct filling of the reaction vessel, opening of the unit after reaction of the waste, or during vented batch treatment. These releases are considered to be emission sources for the risk assessment.

II.5.2.12   Water Reactor

The water reactor is a new piece of bench-scale equipment that will be used to deactivate water-reactive waste in compliance with LDR treatment standards. The water reactor will be designed to control the rate of reaction, dissipate exothermic heat generation, and manage product off-gases safely. At the present time, the final design for the water reactor is being developed. Conceptually, the water reactor is an adaptation of the pressure reactor to introduce a humid gas into the reaction vessel to sustain a controlled reaction of water-reactive waste materials. The water reactor will normally be located in the small-scale treatment laboratory, where emissions will be controlled by a combination of an acid gas scrubber, HEPA filter, and carbon columns (See **Figure II-8**).

The treatment process starts with transferring water-reactive waste from an air-tight storage container into the pressure vessel. The transfer operations will be conducted inside a glove box so that a dry, inert atmosphere can be maintained to preclude uncontrolled reactions if the waste were to be exposed to humid air. To ensure adequate head space is maintained, the treatment process will be conducted in small batches that will not exceed 75 percent of the vessel's capacity, which will be approximately 1 L.

Because the treatment process generates hydrogen gas, an inert carrier gas (e.g., nitrogen) will be used to prevent the formation of an explosive mixture of hydrogen and air. The rate of the

deactivation reaction will be controlled by adjusting the flow and/or relative humidity of the inert nitrogen carrier gas. Cold water will typically be used to dissipate heat from the exothermic reaction. The temperature and pressure of the reaction vessel are continuously monitored. The flow of nitrogen gas to the pressure reactor will be immediately stopped should abnormal readings be observed. For specific applications, the water reactor may be used at a lab bench within the small-scale treatment laboratory or within the reactive waste processing room. If required, a bench-scale off-gas treatment system will be assembled to treat specific reaction products. Because the final design for the water reactor is still under development, it is assumed that, analogous to the pressure reactor, gaseous and particulate releases may occur during loading and waste treatment. As such, this unit represents an emission source for the risk assessment.

II.5.2.13 Amalgamation Reactor

The amalgamation reactor is a new piece of bench-scale equipment that will be used to amalgam elemental mercury. Amalgamated mercury is more amenable for land disposal than liquid mercury because it is a solid and has a lower vapor pressure. Zinc will typically be used to form the amalgam alloy.

The amalgamation reactor is a bench-scale vessel with an approximate capacity of 1 L. Elemental mercury will be treated on a batch basis. The liquid mercury will typically be placed on the bottom of the reaction vessel with the zinc on top. The reactor will contain an electric heater (to achieve the high temperatures needed to melt the zinc) and a stirrer to mix the two metals. After mixing, the stirrer will be removed. As the temperature of the vessel lowers, the mixture of mercury and zinc hardens into a solid alloy.

The amalgamation process will be conducted in an inert atmospheric glove box. Off-gases from the reactor will be collected in a lecture bottle, using a vacuum pump for storage or off-site shipment for further treatment and/or disposal. Releases of mercury vapor and volatile organic compounds may take place when waste containers are opened prior to placement of waste into the amalgamation unit. Consequently, this unit is considered an emission source for the risk assessment. However, because the wastes designated for this unit are predominately mercury, particulate releases are expected to be insignificant.

II.5.2.14 Other Nonroutine Small-Scale Treatment Processes

Because LLNL conducts a wide variety of research experiments, many different types of hazardous wastes are generated. There are occasions when a research project will generate a waste matrix that can neither be treated on site using the dedicated equipment previously described in this section or shipped off site to a commercial facility. These wastes are generally in 5-gal carboy containers, lab bottles, or some other small container. Waste gases are in gas cylinders. Although treating the waste may be technically feasible, installing dedicated equipment to treat wastes that are generated infrequently and in limited quantities is neither practicable nor cost effective. As such, laboratory-scale equipment will be assembled on an as-needed basis to treat these non-routinely generated, unique wastes.

The non-dedicated treatment systems will be operated either in the reactive waste processing area or the small-scale treatment laboratory in Building 695. The small-scale treatment processes include almost every LDR-specified treatment technology except incineration technologies. All of the treatment processes identified in **Table II-3** may be conducted on a bench-scale basis. Those treatment processes annotated by an asterisk are restricted to small-scale treatment. Small-scale treatment may also be used to optimize any of the dedicated treatment systems (small- or large-scale processes). Cylinders containing waste gases may be processed for treatment using adsorption system (see **Section II.5.2.9**).

The nonroutine, small-scale treatment equipment will consist of commonly used "lab ware," such as reactors, containers, columns, small electric heaters, stirrers, in-line mixers, shell and tube exchangers, chillers, small filters, sampling chambers, tubing, fittings, pressure transducers, thermocouples, pH probes, and ion specific electrodes. The primary suppliers of this equipment are Cole-Parmer (an instrument company that sells process equipment for laboratory bench-scale activities) and Swagelok (a company that sells tubing and fittings). The capacity of the small-scale equipment will typically be operated using 1/4-in.-diameter tubing. Equipment with fittings in excess of 1/2-in. diameter will not be used. Control of the small-scale treatment system will either be manual or will use programmable logic controls manufactured by National Instruments Lab-View system (or equivalent). Lab-View systems' programmable logic controls are specifically designed for laboratory experimentation systems.

Typical small-scale treatment operations will be conducted in ventilation hoods or glove boxes, depending on the type of treatment necessary. Ventilation hoods in the reactive waste processing area and the small-scale treatment laboratory will be connected to a carbon/scrubber unit and to the building HEPA filters. Glove boxes will have controlled exhaust systems, including HEPA filtration.

Prior to conducting a non-routine, small-scale treatment process, a treatment plan will be prepared under the direction of the HWM Division review chemist and/or process engineer and submitted to DTSC for concurrence. Information in the treatment plan will include, where applicable, the type of information required to be submitted for treatability studies. The treatment will be conducted as described in the treatment plan no sooner than 30 days after notification has been made to DTSC unless otherwise instructed by DTSC. If containment and/or ventilation controls are required, the small-scale treatment process will be conducted inside a glove box or hood. If required, a bench-scale, off-gas treatment system will be assembled to treat specific reaction products.

Small-scale treatment processes, including uranium bleaching, pressure reactor, water reactor, and amalgamation, account for less than 1 percent of the treatment capacity listed in the RCRA Part A permit application (LLNL, 1996). Nonroutine, small-scale treatment processes, when considered alone, make up a small fraction of the small-scale treatment capacity. Because these processes are non-routine, the waste volumes are small, and operations will be conducted in appropriate ventilation systems, the contribution of nonroutine small-scale treatment emissions to the total health risk associated with operating DWTF are expected to be negligible. Therefore, emissions from nonroutine, small-scale treatment operations are not included in the calculation of the DWTF source term.

II.5.3 Waste Decision Criteria

Each of the treatment processes described in **Sections II.5.1** and **II.5.2** is designed to treat specific types of waste either alone or as part of a treatment train. Some waste may be adequately treated using more than one treatment process. When multiple alternatives exist, the cost and treatment effectiveness of each potential treatment process will be evaluated to determine the most suitable treatment method. The criteria for determining the appropriateness for treating various waste streams are shown in **Figure II-6**. These criteria are graphically depicted in **Figure II-9** through **Figure I-11**. These figures are as presented in the Waste Analysis Plan that was included with the Part B Permit Application (LLNL, 1996). Because many of the treatment systems have not been used at LLNL, these decision criteria are used as the bases to quantify potential emissions from these sources.

II.6 Waste Transfers and Off-Site Shipments

Whenever practicable and cost effective, hazardous waste are shipped off site to permitted TSD facilities for management. Hazardous waste shipped off site are packaged and labeled in accordance with applicable U.S. Environmental Protection Agency (EPA), DOT, and DTSC requirements for transportation. Small quantities of compatible waste are typically blended together (e.g., consolidated) to reduce transportation and off-site TSD facility costs. The combination of different waste streams is first planned and approved by appropriate HWM staff.

Compatible wastes from two or more containers may be consolidated into a single, common container to maximize the use of on-site storage spaces and to reduce off-site transportation and TSD costs. Waste streams are also combined to allow subsequent treatment processes to operate more efficiently. Wastes that could result in the evolution of gaseous emissions will not be combined in a storage unit.

Liquid waste is typically shipped off site in vacuum tankers that originate either from the Area 612 Facility or from the DWTF facility. Wastes from containers and portable tanks are transferred into the tanker by the vacuum suction line (stinger) on the tanker or by an external pump with submerged-fill discharge into the tanker. The tanker truck may or may not be equipped with emission control equipment, such as a carbon adsorption system.

Waste transfer source terms are included in the risk assessment for the Area 612 Facility and for the DWTF Facility. For the purposes of the risk assessment, it is assumed that the air displaced from the filling operations contains volatile organic compounds in gaseous or vapor form and is dispersed directly to the atmosphere from the top of the tanker truck, without emission control other than submerged-fill discharge. As with other processes, historical records have been tabulated to formulate the list of compounds potentially released (i.e., the source term) as described in **Section III**.

II.7 Summary of Risk Assessment Emission Sources

In summary, the sources of emissions for this risk assessment are from the Building 695 Storage/Treatment Unit Group and the Area 612 Container Storage/Treatment Unit Group.

These facilities will treat RCRA hazardous, mixed, and non-RCRA hazardous wastes in treatment units that may be exposed to the atmosphere. The risk assessment assumes that all of the volatile organic compounds contained in the waste treated by the facility are emitted to the atmosphere, unless the emissions are abated by an air pollution control device. During the process of bulking or transferring wastes at either of the two Unit Groups, containers are opened, mixing occurs, and the potential for volatile organic chemicals to be emitted to the atmosphere exists.

The specific units that are emission sources for the risk assessment and the general types of emissions from each unit are noted in **Table II-1**.

The Building 280 Container Storage Unit and the Building 693 Container Storage Unit Group will primarily be used for waste storage and are not considered sources for this risk assessment.

II.8   References

California Code of Regulations (CCR). 1995. Title 22, Chapter 11, *Identification and Listing of Hazardous Waste*, Part 66261. Health and Welfare Agency, Sacramento, CA (22 CCR 66261).

California Code of Regulations (CCR). 1995. Title 22, Chapter 11, *Identification and Listing of Hazardous Waste*, Part 66261.7, Contaminated Containers. Health and Welfare Agency, Sacramento, CA (22 CCR 66261.7).

California Code of Regulations (CCR). 1995. Title 22, Chapter 14, *Standards for Owners and Operators of Hazardous Waste Transfer, Treatment, Storage, and Disposal Facilities*, Part 66264.316, Disposal of Small Containers of Hazardous Waste in Overpacked Drums. Health and Welfare Agency, Sacramento, CA (22 CCR 66264.316).

California Code of Regulations (CCR). 1995. Title 22, *Environmental Health Standards— Hazardous Waste*. Health and Welfare Agency, State of California, Sacramento, CA.

California Code of Regulations (CCR). Title 22, Chapter 18, *Land Disposal Restrictions,* Part 66268.32, Waste Specific Prohibitions—California List Wastes. Health and Welfare Agency, Sacramento, CA (22 CCR 66268.32).

California Code of Regulations (CCR). Title 22, Chapter 18, *Land Disposal Restrictions,* Part 66268.42, Treatment Standards Expressed as Specified Technologies. Health and Welfare Agency, Sacramento, CA (22 CCR 66268.42).

California Code of Regulations (CCR). Title 22, Chapter 18, *Land Disposal Restrictions,* Part 66268.45, Treatment Standards for Hazardous Debris. Health and Welfare Agency, Sacramento, CA (22 CCR 66268.45).

Code of Federal Regulations (CFR). Title 40, Section 261, *Identification and Listing of Hazardous Waste*. Office of the Federal Register, Washington, D.C. (40 CFR 261).

Code of Federal Regulations (CFR). Title 49, *Transportation,* Subchapter C, Hazardous Materials Regulations. Office of the Federal Register, Washington, D.C. (49 CFR Subchapter C).

Lawrence Livermore National Laboratory (LLNL). 1996. *Resource Conservation and Recovery Act Part B Permit Application, Hazardous Waste Treatment and Storage Facilities*. Lawrence Livermore National Laboratory, Livermore, CA.

McDowell-Boyer, Laura; Jeff Daniels; Gretchen Gallegos; Frank Gouveia; and Linda Hall. 1995. *Health Risk Assessment for Hazardous and Mixed Waste Management Units at Lawrence Livermore National Laboratory, 1995*. (1995 Health Risk Assessment [HRA]). Lawrence Livermore National Laboratory, Livermore, CA. UCRL-AR-119482.

Resource Conservation and Recovery Act (RCRA. 1976. Public Law 94-580.

II.9   Acronyms

AEA   Atomic Energy Act

DOE   U.S. Department of Energy

DTSC   Department of Toxic Substances Control

DWTF   Decontamination and Waste Treatment Facility

EPA   U.S. Environmental Protection Agency

HEPA   High-efficiency particulate air

HWM   Hazardous Waste Management

LDR   Land Disposal Restriction

LLNL   Lawrence Livermore National Laboratory

LWPB   Liquid Waste Processing Building

LWRP   Livermore Water Reclamation Plant

PCB   Polychlorinated biphenyl

PID   Photo ionization detector

RCRA   Resource Conservation and Recovery Act

RWP   Reactive waste processing

SOP   Standard operating procedure

SSTL   Small-Scale Treatment Laboratory

TRU   Transuranic

TSCA   Toxic Substances Control Act

TSD   Treatment, storage, and disposal

WAA   Waste Accumulation Area

WDR   Waste Disposal Requisition
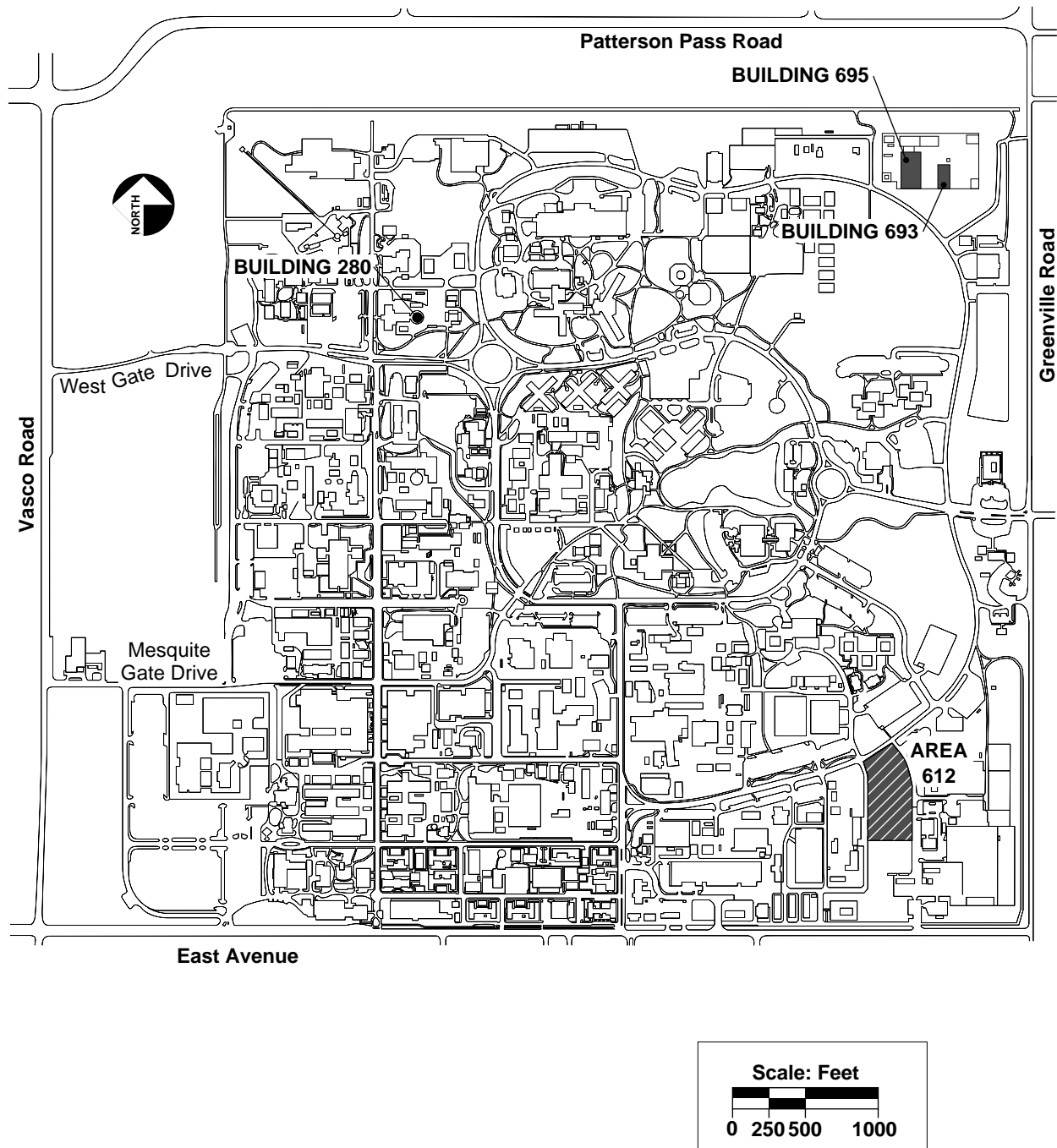
Figure II-1.   Hazardous Waste Storage/Treatment Unit Location Map
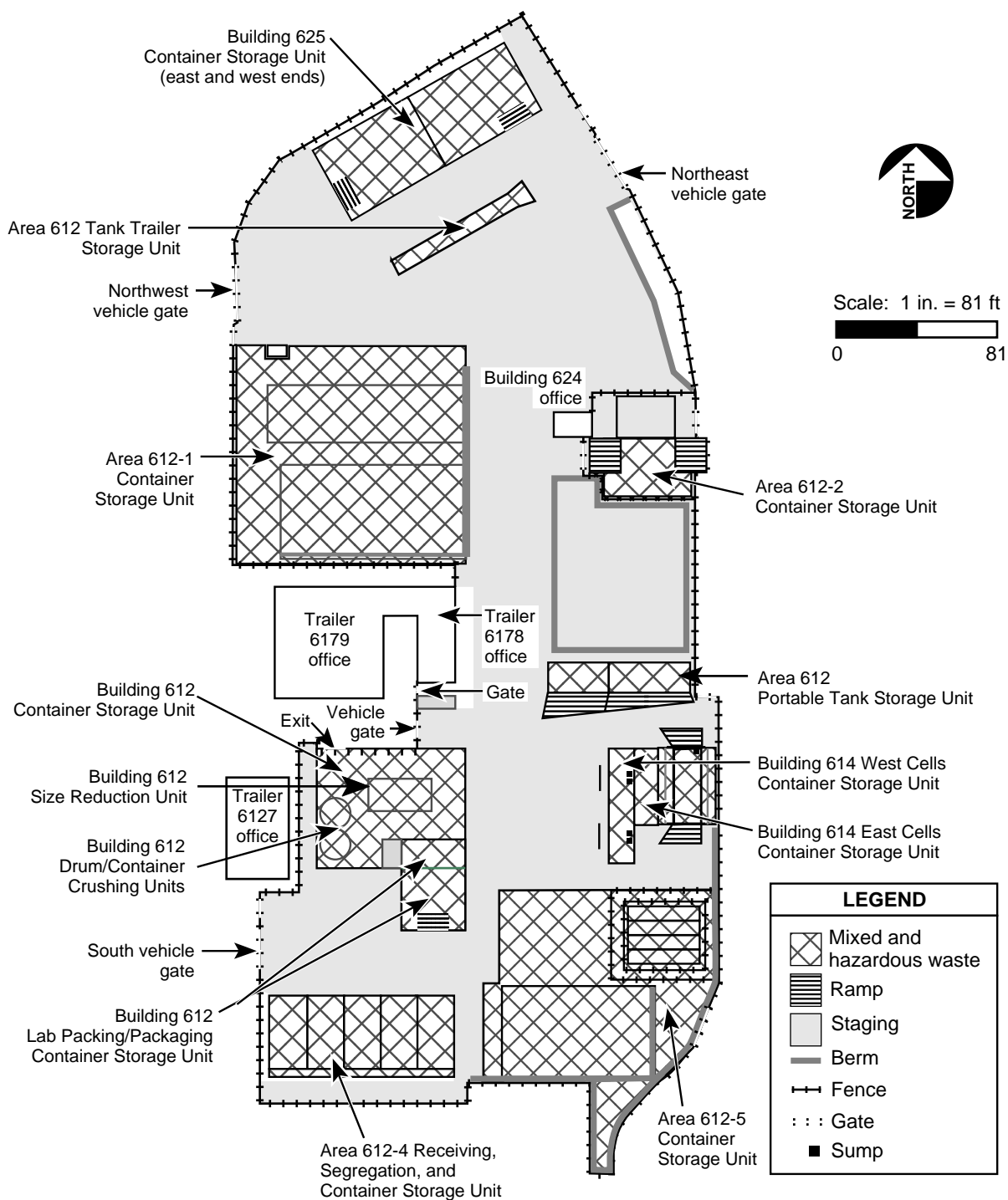
Figure II-2.   Area 612 Container Storage/Treatment Unit Group Layout

Laboratory
Building 281
(not part of
HWM Facility)

Exit

Ramp down
1:10 Slope

Unused building
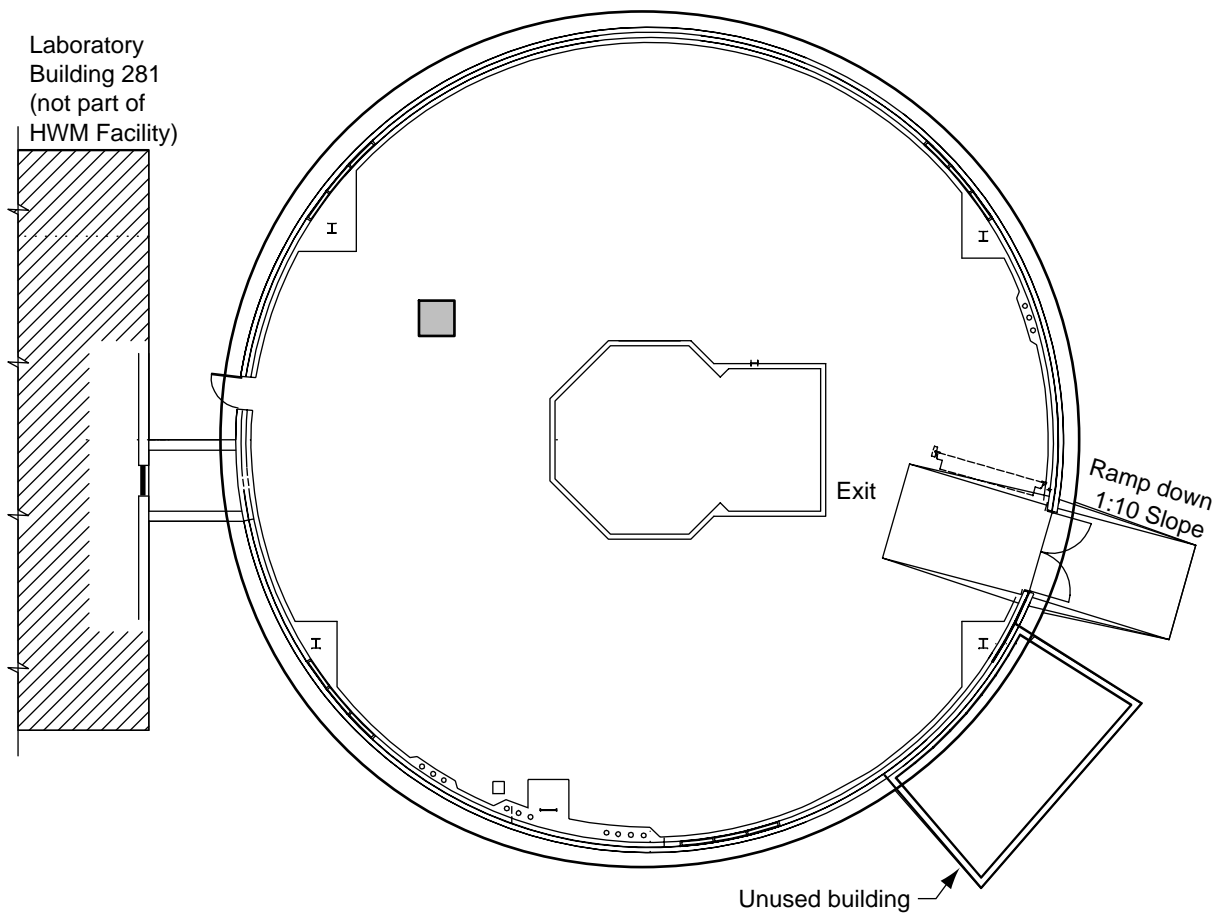
Figure II-3.   Building 280 Container Storage Unit Layout
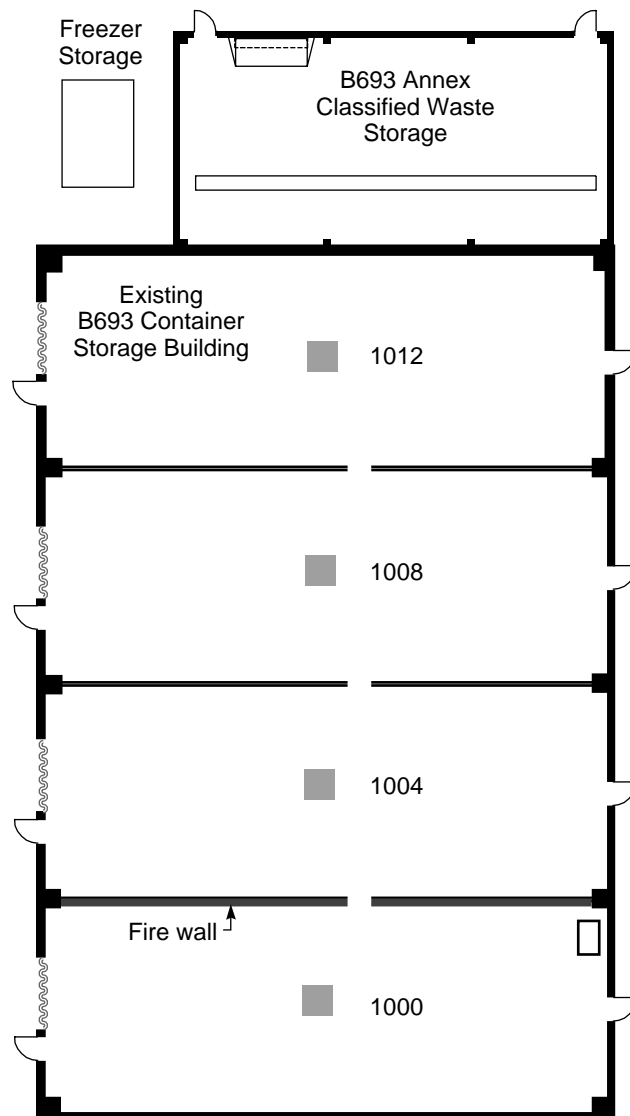
Figure II-4.   Building 693 Container Storage Unit Group Layout
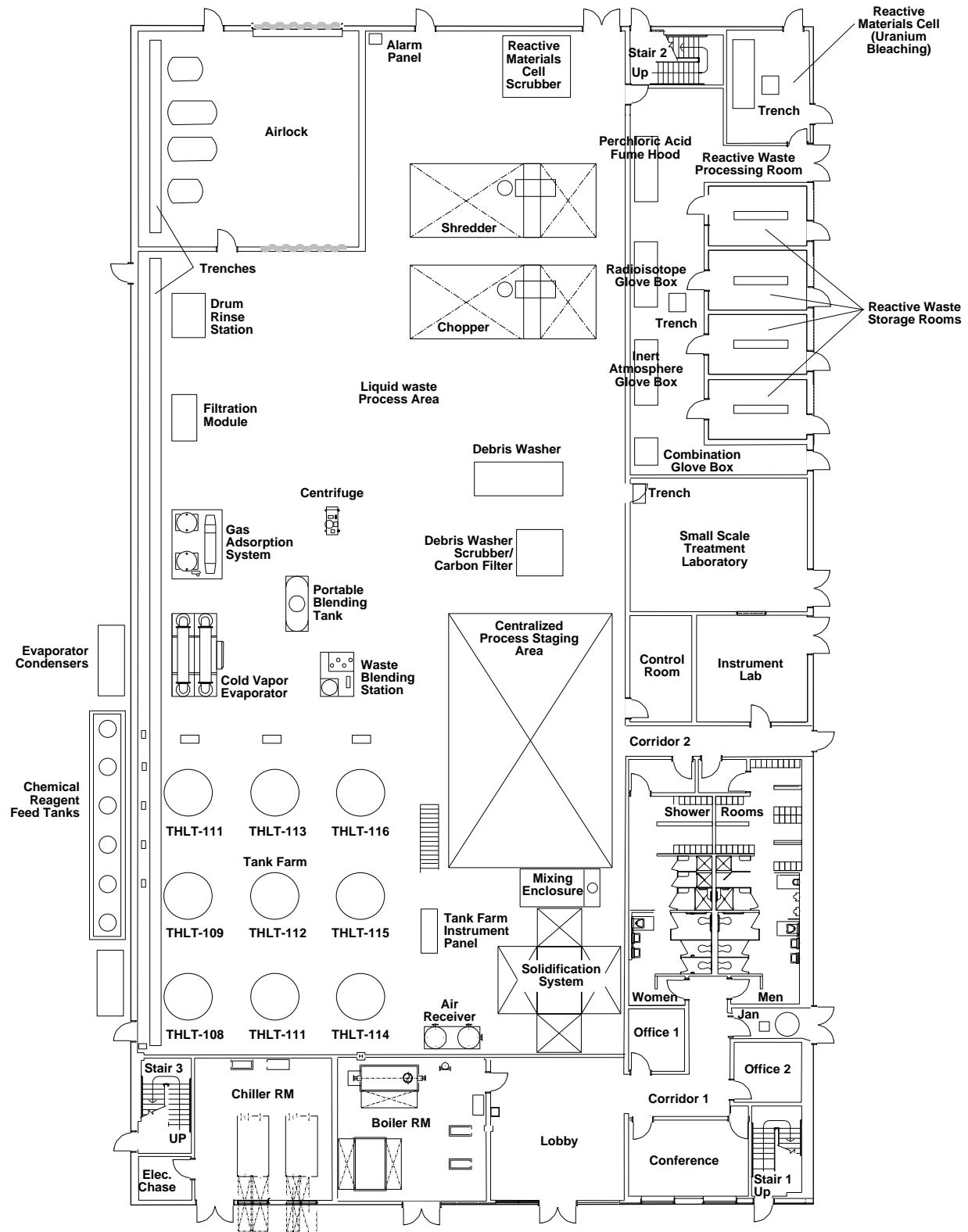
Figure II-5.   Building 695 Storage/Treatment Unit Group Layout
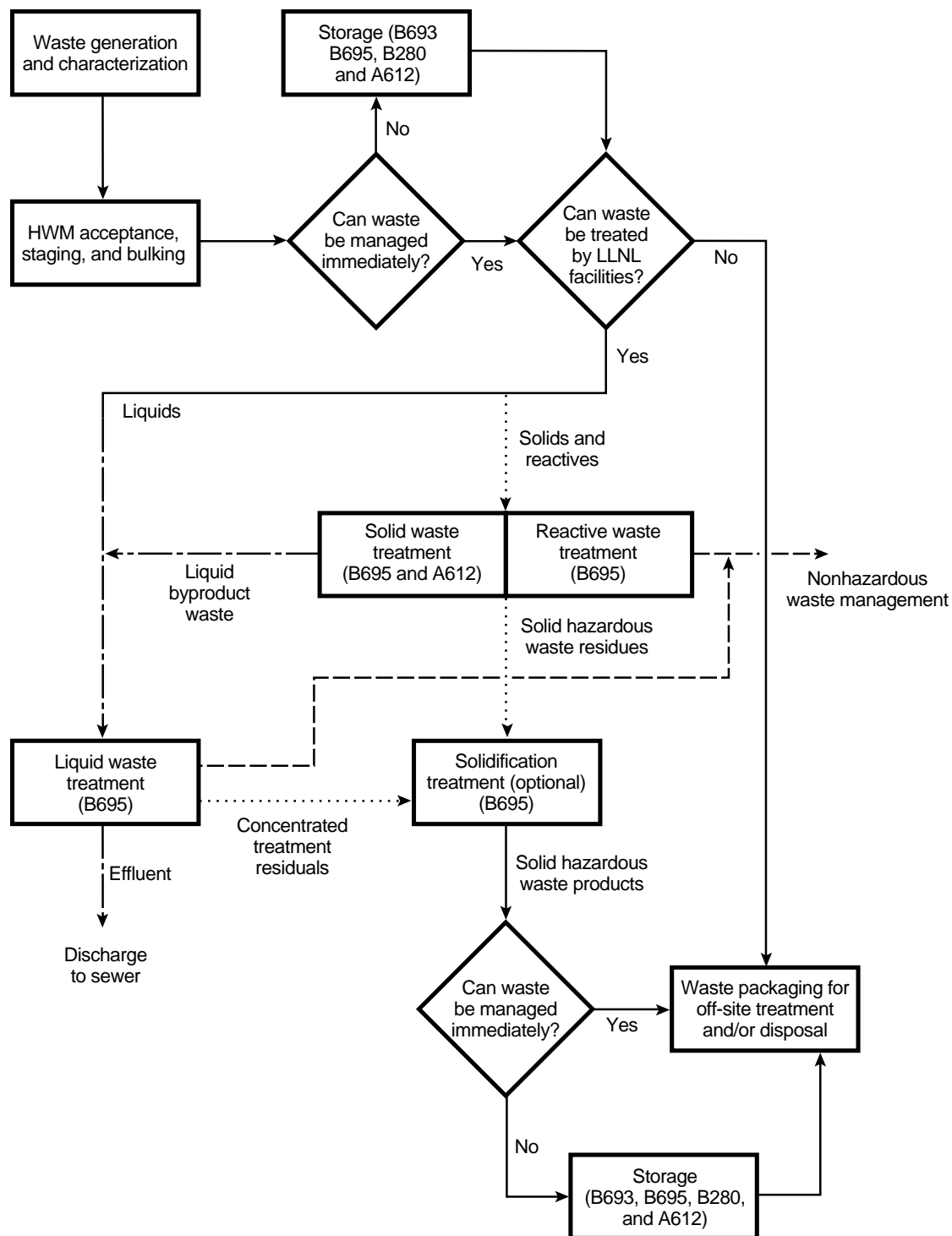
Figure II-6.   Hazardous Waste Management Process Flow
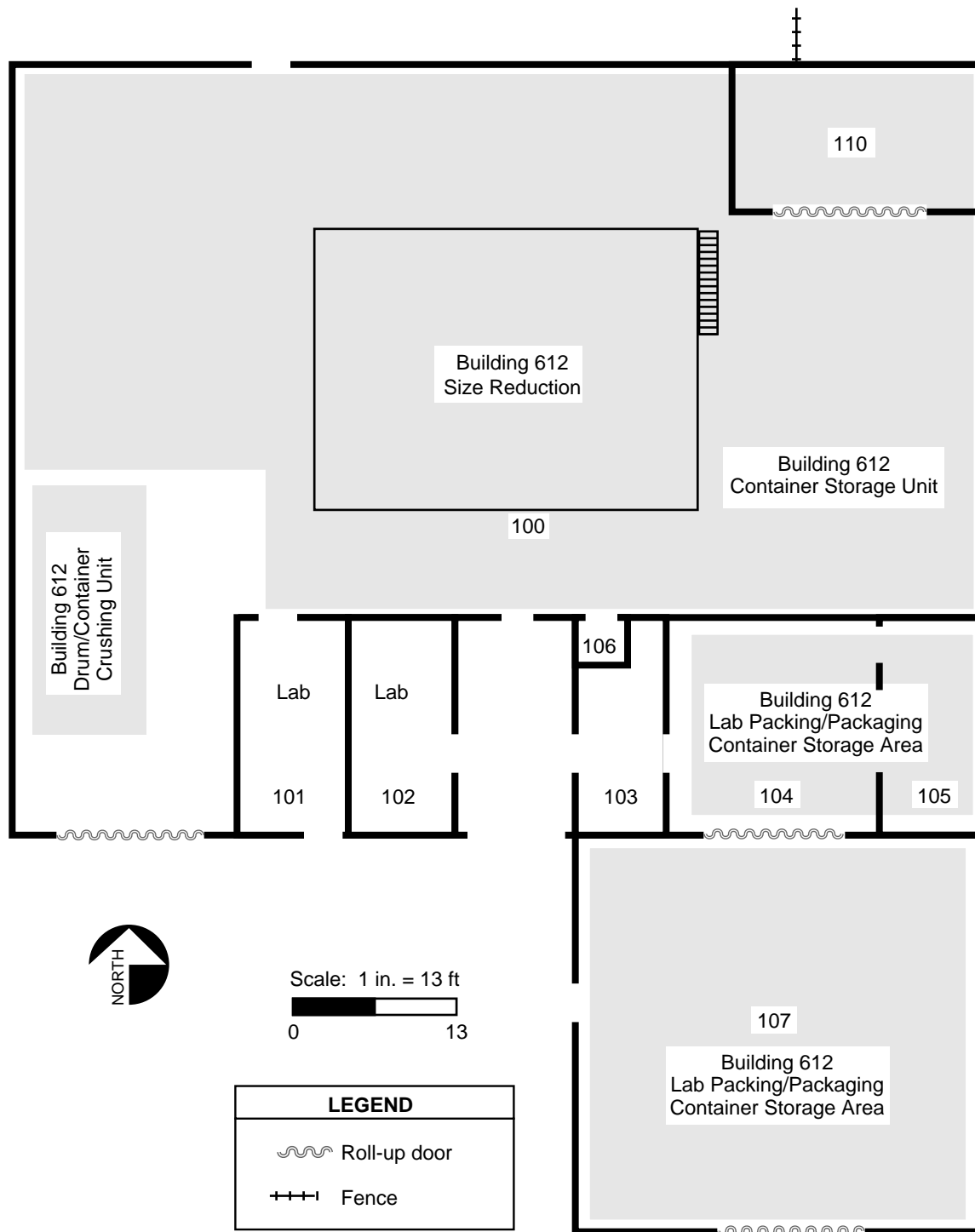
Figure II-7.   Building 612 Layout
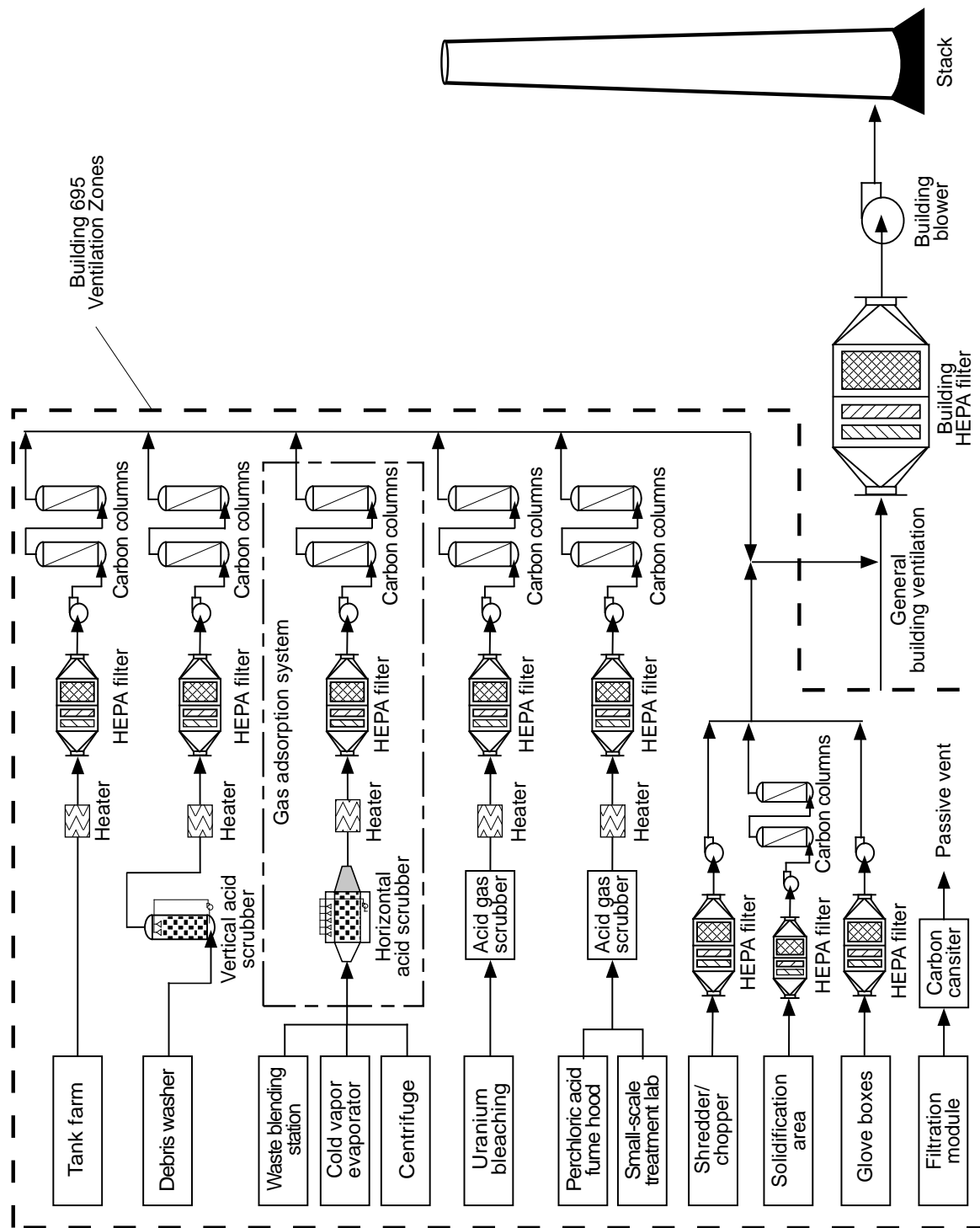
Figure II-8.   Building 695 Process Ventilation System
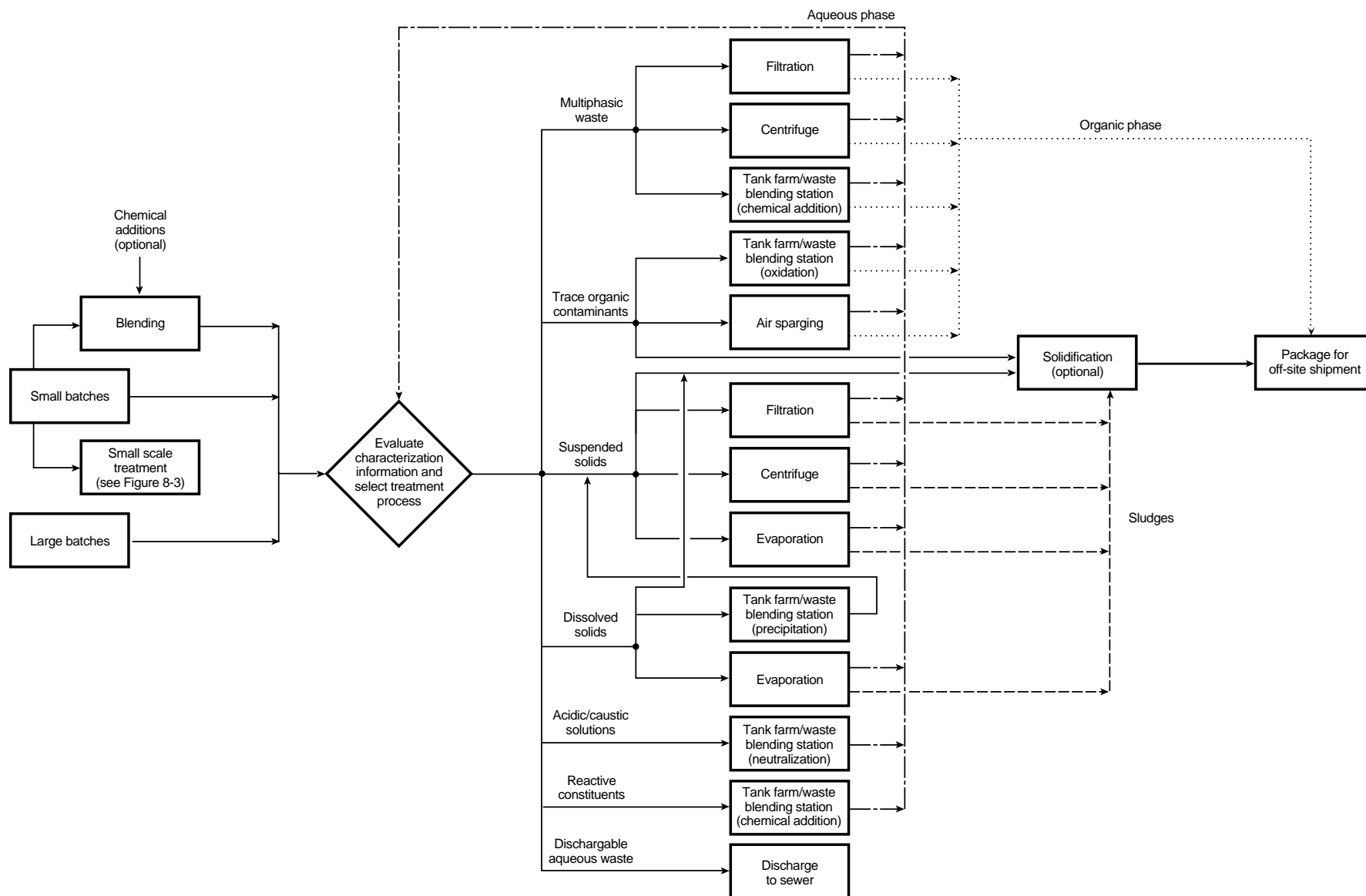
Figure II-9.   Liquid Waste Treatment Decision Tree
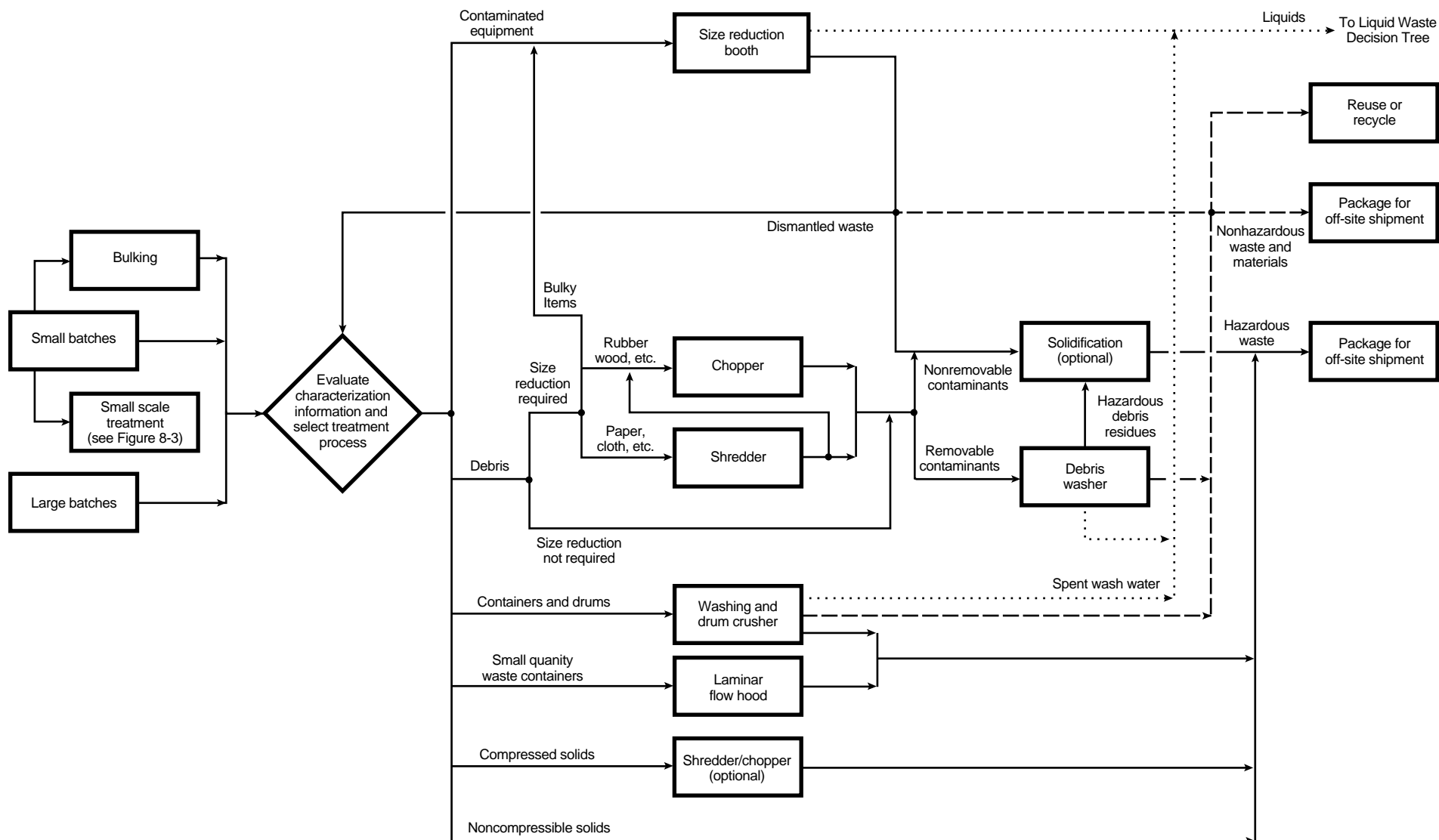
Figure II-10.   Solid Waste Treatment Decision Tree
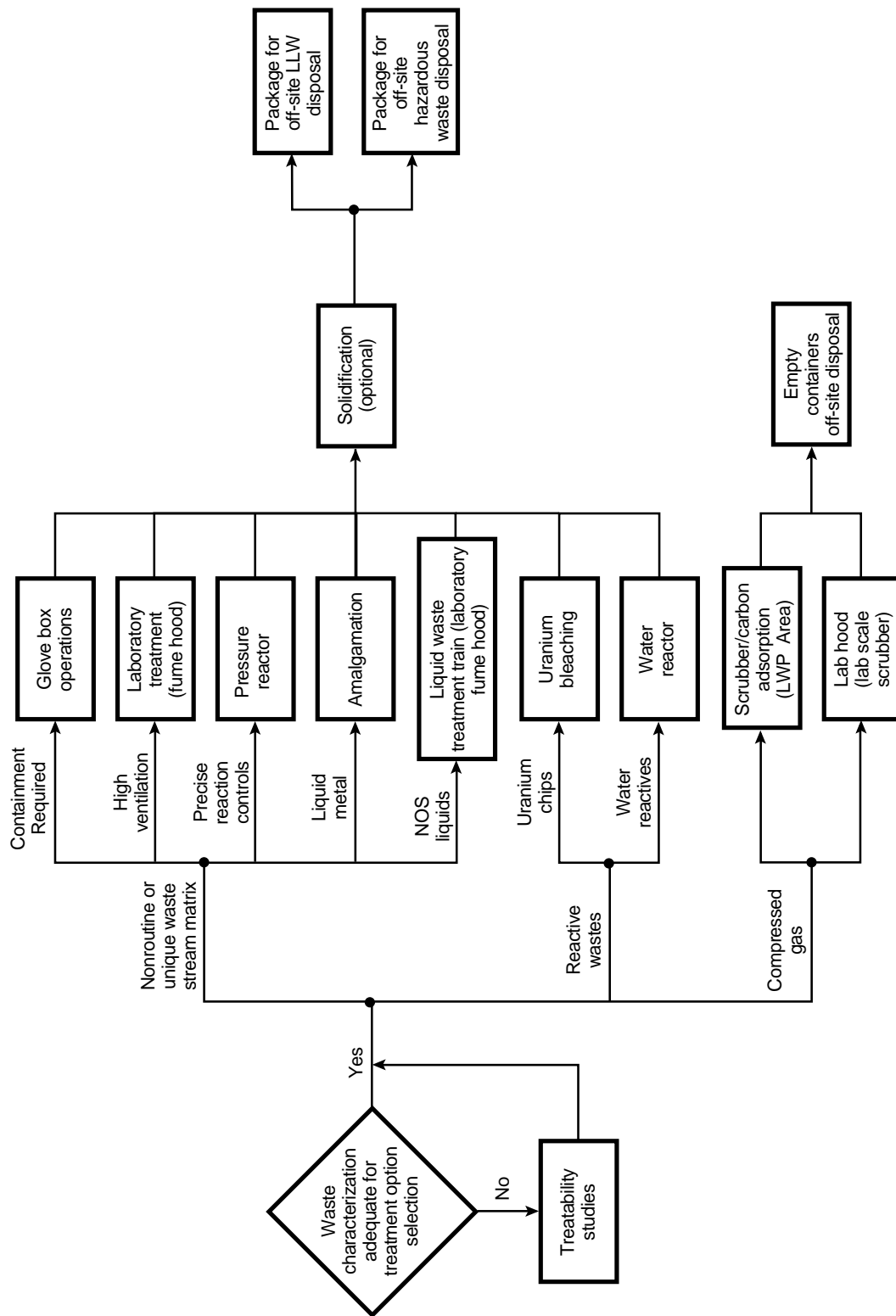
Figure II-11.   Small-Scale Treatment Decision Tree

Table II-1.   Waste Managed by the HWM Storage Unit/Treatment System

Name of Storage[1] or Treatment Unit	Waste Types[2] Stored Managed in Unit	Waste Streams[3] by Form Code			Risk[4] Assessment Emission Source
Area 612 Container Storage/Treatment Unit Group					
Area 612-4 Receiving, Segregation, and Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous (includes TSCA-regulated, PCB liquids), asbestos; liquid, solid, and gas	All form codes			No
Area 612 Portable Tank Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and solid	101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 119 201 202 203 204 205 206 207 208 210 211 212 219 301 302 304 306 307 310 312 313 315 316 319 401 402 403 404 405 407 409 503 504 505 506 509 512 513 514 515 519 603 604 605 608 609			No
Area 612 Tank Trailer Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and solid	101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 119 201 202 203 204 205 206 207 208 210 211 212 219 301 302 304 306 307 310 312 313 315 316 319 401 402 403 404 405 407 409 503 504 505 506 509 512 513 514 515 519 603 604 605 608 609			No

Table II-1. Continued

Name of Storage[1] or Treatment Unit	Waste Types[2] Stored Managed in Unit	Waste Streams[3] by Form Code	Risk[4] Assessment Emission Source
Area 612-1 Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous (includes TRU); solid	001 002 003 004 009 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 319 401 402 403 404 405 406 407 409	No
Area 612-5 Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous (includes TRU); solid	001 002 003 004 009 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 319 401 402 403 404 405 406 407 409	No
Building 612 Drum/ Container Crushing Units (X02)[d]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and solid	301 304 305 306 307 308 309 310 311 312 313 314 316 319 401 402 403 404 406 407 409 503 504 519 604	No
Building 612 Size Reduction Unit (X99)[e]	RCRA hazardous, mixed, nonRCRA hazardous; liquid, solid, and gas	All form codes	Yes (particulates and volatile compounds)
Building 612 Lab Packing/ Packaging Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid, solid, and gas	All form codes	No
Building 612 Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid, solid, and gas	All form codes	No
Building 614 West Cells Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid, solid, and gas	All form codes	No
Building 614 East Cells Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid, solid, and gas	All form codes	No
Area 612-2 Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and solid	All form codes	No

Table II-1. Continued

Name of Storage[1] or Treatment Unit	Waste Types[2] Stored Managed in Unit	Waste Streams[3] by Form Code	Risk[4] Assessment Emission Source
Building 625 Container Storage Unit (S01)[a]	RCRA hazardous, mixed, and nonRCRA hazardous (includes TRU and TSCA-regulated PCB liquids), asbestos; liquid, solid, and gas	All form codes	No
Building 280 Container Storage Unit			
Building 280 Container Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous (includes TRU); solid	001 002 003 004 009 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 319 401 402 403 404 405 406 407 409	No
Building 693 Container Storage Unit Group			
Building 693 Container Storage Unit Group (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid, solid, and gas	All form codes	No
Building 693 Annex Classified Waste Storage	RCRA hazardous, mixed, nonRCRA hazardous; solid	All form codes	No
Building 693 Yard— Freezer Storage Unit (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and solid	009 103 104 609	No
Building 693 Yard—Roll-Off Bin Storage (S01)[a]	RCRA hazardous, nonRCRA hazardous; solid	302 307 308 319 406	No
Building 695 Container Storage/Treatment Unit Group			
Building 695 Liquid Waste Processing Area (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and solid	All form codes	No

Table II-1.   Continued

Name of Storage[1] or Treatment Unit	Waste Types[2] Stored Managed in Unit	Waste Streams[3] by Form Code			Risk[4] Assessment Emission Source
Building 695 Liquid Waste Processing Area, Tank Farm (S02,[b] T01[c])	RCRA hazardous, mixed, nonRCRA hazardous; liquid and sludge	101	102	106	Yes (volatile compounds)
		107	108	109	
		110	111	112	
		113	114	115	
		116	119	201	
		202	203	204	
		205	206	207	
		211	219	305	
		306	313	314	
		315	316	319	
		501	502	503	
		504	505	506	
		507	508	509	
		510	511	512	
		513	514	515	
		516	519	607	
		608	609		
Building 695 Liquid Waste Processing Area, Waste Blending Station (X99)[e]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and sludge	101	102	106	Yes (subset of tank farm)
		107	108	109	
		110	111	112	
		113	114	115	
		116	119	201	
		202	203	204	
		205	206	207	
		211	219	305	
		306	313	314	
		315	316	319	
		501	502	503	
		504	505	506	
		507	508	509	
		510	511	512	
		513	514	515	
		516	519	607	
		608	609		
Building 695 Liquid Waste Processing Area Cold Vapor Evaporator (X99)[e]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and sludge	101	102	106	Yes (subset of tank farm)
		107	108	109	
		110	111	112	
		113	114	115	
		116	119	201	
		202	203	204	
		205	206	207	
		211	219	501	
		502	503	504	
		505	506	507	
		508	509	510	
		511	512	513	
		514	515	516	
		519	607	608	
		609			

Table II-1.   Continued

Name of Storage[1] or Treatment Unit	Waste Types[2] Stored Managed in Unit	Waste Streams[3] by Form Code			Risk[4] Assessment Emission Source
Building 695 Liquid Waste Processing Area, Centrifuge (X99)[e]	RCRA hazardous, mixed, nonRCRA hazardous; liquid	101 107 110 113 116 202 205 211 519 609	102 108 111 114 119 203 206 219 607	106 109 112 115 201 204 207 516 608	Yes (treated volatile compounds)
Building 695 Liquid Waste Processing Area, Filtration Module (X99)[e]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and sludge	101 107 110 113 116 202 205 211 502 505 508 511 514 519 609	102 108 111 114 119 203 206 219 503 506 509 512 515 607	106 109 112 115 201 204 207 501 504 507 510 513 516 608	Yes (residual off-gases)
Building 695 Liquid Waste Processing Area, Shredder/Chopper (X02)[d]	RCRA hazardous, mixed, nonRCRA hazardous; solid and sludge	307 319	308 406	310	Yes (residual particulates and volatile compounds)
Building 695 Liquid Waste Processing Area, Debris Washer (X99)[e]	RCRA hazardous, mixed, nonRCRA hazardous; solid and sludge	307 319 504 507 510 513 516 608	308 406 505 508 511 514 519 609	310 503 506 509 512 515 607	Yes (treated off-gases and particulates)

Table II-1.   Continued

Name of Storage[1] or Treatment Unit	Waste Types[2] Stored Managed in Unit	Waste Streams[3] by Form Code	Risk[4] Assessment Emission Source
Building 695 Liquid Waste Processing Area, Solidification System (X99)[e]	RCRA hazardous, mixed, nonRCRA hazardous; liquid, solid, and sludge	101 102 106 107 108 109 110 111 112 113 114 115 116 119 201 202 203 204 205 206 207 211 219 305 306 313 314 315 316 319 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 519 607 608 609	Yes (particulates and volatile compounds)
Building 695 Liquid Waste Processing Area, Gas Adsorption System (X99)[e]	RCRA hazardous, mixed, nonRCRA hazardous; gas	701 801	No See **Section II.5.2.9**
Building 695 Reactive Waste Processing Area and Small Scale Treatment Laboratory (S01,[a] X99[e]) Includes: Uranium Bleaching Process, Pressure Reactor, Water Reactor, Amalgamation Reactor, and Non-Routine Treatment	RCRA hazardous, mixed; liquid, solid, and gas	All form codes	Yes Except for nonroutine, small-scale treatment processes (see **Section II.5.2.14**)
Building 695 Airlock (S01)[a]	RCRA hazardous, mixed, and nonRCRA hazardous; liquid, solid, and gas	All form codes	No
Building 695 Reactive Waste Storage Rooms (S01)[a]	RCRA hazardous, mixed; liquid, solid, and gas	All form codes	No

Table II-1. Continued

Name of Storage[1] or Treatment Unit	Waste Types[2] Stored Managed in Unit	Waste Streams[3] by Form Code			Risk[4] Assessment Emission Source
DWTF Portable Tank Storage Pad (S01)[a]	RCRA hazardous, mixed, nonRCRA hazardous; liquid and solid	101	102	103	No
		104	105	106	
		107	108	109	
		110	111	112	
		113	114	115	
		116	119	201	
		202	203	204	
		205	206	207	
		208	210	211	
		212	219	301	
		302	304	306	
		307	310	312	
		313	315	316	
		319	401	402	
		403	404	405	
		407	409	503	
		504	505	506	
		509	512	513	
		514	515	519	
		603	604	605	
		608	609		

[1] Process codes are as follows:
   [a] S01 = Container storage.
   [b] S02 = Tank storage.
   [c] T01 = Tank treatment.
   [d] X02 = Miscellaneous (other Subpart X) mechanical processing.
   [e] X99 = Miscellaneous (other Subpart X) treatment.

[2] NonRCRA hazardous waste means California-only hazardous waste as defined in 22 CCR 66261. Mixed includes only waste characterized or listed according to RCRA, 40 CFR 261, as hazardous that also has a radioactive constituent. Hazardous waste is defined by 40 CFR 261.

[3] Although incompatible waste codes are listed together, waste management practices will prevent the mixing or contact of incompatible waste.
   PCB = Polychlorinated biphenyl.
   RCRA = Resource Conservation and Recovery Act.
   TRU = Transuranic.
   TSCA = Toxic Substances Control Act.

[4] Risk assessment emission sources:
   Yes—Process off-gases from treatment system were evaluated in the risk assessment.
   No—Container storage unit or treatment system is not considered to be a source of emissions.

Table II-2.   Container Storage Unit Capacities

Name of Storage Unit	Storage Capacity[a] (gal)
Building 280 Container Storage Unit	135,700
Area 612 Tank Trailer Storage Unit	10,000
Area 612 Portable Tank Storage Unit	10,000
Building 612 Container Storage Unit	*58,196*
Building 612 Lab Packing/ Packaging Container Storage Unit	4,242
Area 612-1 Container Storage Unit	287,244
Area 612-2 Container Storage Unit	10,560
Area 612-4 Receiving, Segregation, & Container Storage Unit	44,680
Area 612-5 Container Storage Unit	200,990
Building 614 East Cells Container Storage Unit	3,520
Building 614 West Cells Container Storage Unit	672
Building 625 Container Storage Unit	42,416
Building 693 Container Storage Cells	141,240
Building 693 Annex - Classified Waste Storage	22,880
Building 693 Yard - Freezer Storage	1,900
Building 693 Yard - Roll-Off Bin Storage	16,200
Building 695 Liquid Waste Processing Area Container Storage	95,750
Building 695 Airlock Container Storage	12,000
Building 695 Reactive Waste Processing (includes reactive materials cell)	3,600
Building 695 Reactive Waste Storage Rooms	12,400
Building 695 Small Scale Treatment Laboratory	2,000
Building 695 DWTF Portable Tank Storage Pad	<u>30,000</u>
TOTAL	1,146,190

[a]   Storage capacity includes liquid, solid, and gaseous wastes.

Table II-3.   On-Site Treatment Processes

Process Codes[a]	Treatment Processes	Process Codes	Treatment Processes
	Treatment—Chemical		**Treatment—Physical Removal**
T21	Chemical fixation	T48*	Absorption-molecular sieve
T22	Chemical oxidation	T49	Activated carbon
T23	Chemical precipitation	T50	Blending
T24	Chemical reduction	T51*	Catalysis
T25	Chlorination	T53*	Dialysis
T27	Cyanide destruction	T54*	Distillation
T28*	Degradation	T55*	Electrodialysis
T29	Detoxification	T56*	Electrolysis
T30	Ion exchange	T57	Evaporation
T31	Neutralization	T59	Leaching
T32*	Ozonation	T60*	Liquid ion exchange
T33*	Photolysis	T61*	Liquid-liquid extraction
T34A*	Other—Amalgamation	T62	Reverse osmosis
T34B*	Other—Controlled water reaction	T63*	Solvent recovery
T34C*	Other—Gas adsorption	T64	Stripping
		T66A	Other—Drying
		T66B	Other—Container rinsing
	Treatment—Physical Separation		**Treatment—Biological**
T35	Centrifugation	T67*	Activated sludge
T36	Clarification	T69*	Aerobic tank
T37	Coagulation	T75*	Trickling filter
T38	Decanting		
T39	Encapsulation		
T40	Filtration		
T41	Flocculation		
T44	Sedimentation		
T45	Thickening		
T46	Ultrafiltration		
T47A	Other—Size reduction		
T47B	Other—Segregation		
T47C*	Other—Retorting		

a   Process codes are taken from 22 CCR 66264, Appendix I, and are intended for recordkeeping and reporting purposes. These process codes are used as the basis for "permitted" treatment activities that may be conducted in the HWM Facility miscellaneous treatment areas. Those process codes marked with an asterisk (*) are restricted to use in small-scale treatment.

Table II-4.   Types of Hazardous Waste to be Processed in the Treatment Systems

Treatment System Name	Hazardous/Mixed Waste Forms To Be Processed								
	Lab Packs	Inorganic Liquids	Organic Liquids	Inorganic Solids	Organic Solids	Inorganic Sludges	Organic Sludges	Inorganic Gases	Organic Gases
Drum/Container Crushing Units				●	●	●	●		
Size Reduction Unit	●	●	●	●	●	●	●	●	●
Lab Packing/Packaging Container Storage Unit	●	●	●	●	●	●	●	●	●
Tank Farm		●	●	●		●	●		
Waste Blending Station		●	●	●		●	●		
Cold Vapor Evaporator		●	●			●	●		
Centrifuge		●	●			●	●		
Filtration Module		●	●			●	●		
Shredder/Chopper				●	●				
Debris Washer				●	●	●	●		
Solidification System		●	●	●	●	●	●		
Gas Adsorption System								●	●
Uranium Bleaching			●	●					
Pressure Reactor		●	●	●	●	●	●		
Water Reactor		●	●	●	●	●	●		
Amalgamation Reactor									
Other Non-Routine Small Scale Treatment Processes		●	●	●	●	●	●	●	●

Section III.

Source Term Assessment

SECTION III. SOURCE TERM ASSESSMENT

III.1   Introduction

To evaluate human health risk posed by hazardous waste management operations at Lawrence Livermore National Laboratory (LLNL), it is necessary to assess the potential for emissions of chemicals and radionuclides to the environment from this facility, and to quantify these emissions. Chemicals or radionuclides that are volatile or are associated with small particulates may become airborne during treatment and handling of wastes containing these constituents. The quantities of chemicals and radionuclides potentially released to the environment are contingent upon the:

- Initial quantity of each waste stream and of each specific chemical or radionuclide in the waste streams to be handled in the LLNL hazardous waste management facilities

- Physical and chemical properties of both the waste streams and the individual constituents

- Handling or treatment processes applied to the waste streams

- Abatement equipment provided.

In **Section II.5**, the process system descriptions for each waste treatment unit include a brief discussion of the processes that may lead to emissions and the type of abatement available. This information was coupled with data derived in this section, characterizing the physical and chemical properties of waste streams treated by these units, to estimate emissions from hazardous waste operations.

The quantities and the types of chemicals and radionuclides in waste streams destined for handling or treatment at the Area 612 Facility or the Decontamination and Waste Treatment Facility (DWTF) are described in **Section III.1**. In **Section III.2**, the development of emission factors, abatement factors, and emission rates of nonradioactive chemicals and radionuclides from the Area 612 Facility and DWTF operations is discussed, and the emission rates are tabulated.

III.2   Waste Characterization

Because LLNL is a research facility, its waste streams can vary over time, depending upon Program funding and changes in the scope or focus of the research being conducted. Although future waste streams cannot be defined with certainty, waste composition in the future is not expected to vary significantly from past waste composition. The methods used to characterize waste that may be treated and handled at the Area 612 Facility and the DWTF rely on the assumption that waste that has been generated over the last several years at LLNL is generally representative of waste that will be treated at these facilities. Under this assumption, the following steps were taken to characterize the waste for evaluation of potential emissions:

- Identification and review of relevant waste records by treatment unit

- Determination of relevant waste volumes by treatment unit

- Identification of waste constituents according to physical form

- Quantification of waste constituents by treatment unit.

III.2.1   *Waste Records*

LLNL maintains records pertaining to the generation, transfer, bulking, sampling, and treatment of on-site waste. A portion of this waste is currently being treated in the Area 514 Tank Farm, some is being stored on site, and some is being shipped off site for treatment and/or disposal. These records are kept in hardcopy (paper) in the form of Waste Disposal Requisitions (WDRs), and electronically in a database maintained by LLNL's Hazardous Waste Management (HWM) Division. More information about procedures in place at LLNL for tracking waste from generation, through treatment, to ultimate disposal is available in the 1996 *Resource Conservation and Recovery Act Part B Permit Application, Hazardous Waste Treatment and Storage Facilities,* Appendix III-A, "Waste Analysis Plan" (LLNL, 1996). The remainder of this section addresses how waste disposal records were used to estimate a source term for this risk assessment.

III.2.1.1   Waste Disposal Requisitions

When waste is generated at LLNL, the generator is responsible for providing all the necessary information to adequately characterize the waste and ensure its proper handling. The generator provides this information by completing a numbered WDR. The WDR information includes the waste's hazardous properties, physical and chemical descriptions, predominant hazardous constituents, radioactive constituents, waste form code, and any quantitative information available, including results from waste analysis. Copies of these WDRs are attached to the waste containers (i.e., drums, carboys, tanks, etc.) and follow the waste from the Waste Accumulation Areas to its final disposition. Final disposition may be either off-site shipment or the HWM treatment units.

Prior to waste transfer to an HWM facility, the information recorded on the WDRs is entered into a database maintained by the HWM Division. This database, presently named the Total Waste Management System (TWMS), contains data carried over from the previous database, data on the entire waste inventory in storage at the startup date for TWMS (i.e., September 30, 1994), and data pertinent to waste management operations that occurred after the TWMS startup date. After waste is transferred to HWM facilities, the storage location and treatment information is also entered into the HWM database for each WDR. Waste that is bulked or transferred from one container to another, or to a vacuum tanker, at the Area 612 Facility is also indicated as such in the HWM database. Thus, this database provides an integrated waste tracking and inventory system for waste that enters the HWM Division facilities.

These electronic records have been used for this risk assessment to develop a representative description of the waste streams that will potentially be treated or handled in the DWTF and the Area 612 Size Reduction Unit. The use of electronic records to characterize waste that is treated at present in the Area 514 Tank Farm, and that will be treated in the DWTF Tank Farm,

Evaporator, and Blending Station was described in the 1995 *Health Risk Assessment for Hazardous Mixed Waste Management Units at Lawrence Livermore National Laboratory* (1995 Health Risk Assessment [HRA]) (McDowell-Boyer *et al.*, 1995), as was the characterization of waste that is bulked or transferred at the Area 612 Facility (**Section II.5.1**). Waste records for these latter units are not discussed further in this section.

III.2.1.2 Data Acquisition

For each unit in the Building 695 Container Storage and Treatment Unit Group and the Area 612 Container Storage and Treatment Unit Group, relevant records of waste that has been received by HWM operations at LLNL and that would potentially be treated in these units were analyzed. These records were acquired via queries of the TWMS database. Because the DWTF and the Area 612 Size Reduction Unit will treat waste that has been stored on site for many years, in addition to newly generated waste, the queries searched the electronic database for the period of time between startup of the TWMS database (September 30, 1994) to April 1, 1996. Records in the database during that time period are relevant to waste that has been stored on site for many years prior to that date and to waste that was transferred to a HWM facility (but may have been shipped or treated) during that time period.

Records considered relevant were identified by developing a set of queries for the TWMS database, based on consideration of waste currently managed in the Area 514 Facility and the Area 612 Facility and that is expected to be treated in units described in **Section II.5** of this assessment. The ultimate objective of developing this set of queries was to obtain separate sets of waste characterization data for each unit of concern. Records considered irrelevant are those documenting waste destined for units from which emissions are considered negligible (see **Table II-1**).

Preliminary data sets were derived for the units of concern, and they are described below. A summary of the criteria by which these sets were developed is given in **Table III-1**. These preliminary sets were later refined. The refinement is discussed in the next section, which addresses the review of these sets.

For waste types that are routinely stored in a specific location in HWM facilities and are to be treated in specific DWTF units, preliminary sets of requisitions based on storage location information alone were extracted from the database. The preliminary requisition data sets for the Uranium Bleaching Process, the Pressure Reactor, the Water Reactor, or the Amalgamation Reactor were extracted by location. The location of wastes destined for the Uranium Bleaching Process (see **Table III-1**) are those wastes that have been stored in Building 513. Waste types destined for either the Pressure Reactor, Water Reactor, and the Amalgamation Reactor consist of reactive wastes that are routinely stored in Building 614 at LLNL. Once preliminary data extractions were made for the Building 614 location, the records were reviewed and assignment of requisitions to the appropriate units was made. Some of these Building 614 records represented waste that would be shipped off site or to other units in the DWTF and, thus, were designated for the appropriate destination.

Solid radioactive and mixed waste representative of waste that would be treated in the Debris Washer, the Shredder/Chopper, and the Size Reduction Unit is stored in Area 612-1,

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Area-612-2, Area 612-5 or Building 612, Room 100 (see **Table III-1**). In addition to location criterion, the waste form (solid, liquid, or gas) and the type (hazardous, radioactive, or mixed) were used to extract preliminary data for these units. The waste type criterion was used to select waste records for waste that is either radioactive or mixed, and the waste form criterion was used to select waste records for wastes that are solid. The resulting data set was assumed to represent waste destined for the Shredder/Chopper and the Size Reduction Unit. Because the Debris Washer will only treat mixed waste, only a portion of the records of this preliminary data set was selected in developing a data set for this unit. Some records for hazardous waste were later added to the Size Reduction Unit's data set, however, representing waste that might be sent to this unit for decontamination before off-site shipment. Therefore, the data set for the Size Reduction Unit is slightly larger than that for the Shredder/Chopper.

For the Solidification System and Filtration Module, the location, waste form and waste type criteria did not offer an adequate description of waste likely to be sent to these units. Therefore, waste form codes were used to extract a preliminary set of appropriate waste records. The location criterion was not adequate because waste to be processed in these units is not typically confined to single storage areas at LLNL. Form codes, listed in **Table III-1**, were specified as the criterion by which preliminary data sets for the Solidification System and Filtration Module were developed. A data set for the Centrifuge Unit was developed as a subset of the records in the Filtration Module data set; this subset contained records that corresponded to the Waste Accumulation Areas of Buildings 321, 321A, and 321C.

The queries of the TWMS database were posed such that, for each requisition that met the search criteria, the following data were extracted:

- Requisition (WDR) number—This number is a unique identifier for generated waste destined for HWM Division's present facilities, whether it is treated in HWM facilities or shipped to an off-site commercial treatment facility.

- Item number—This number identifies an individual waste item covered by a requisition. Some requisitions have only one item; some have many.

- Building number—This is a building number identifier for the LLNL building where the waste was generated.

- Workplace end date—This date is the date on which the waste left the site where it was generated and sent to a Satellite or Waste Accumulation Area before coming over to the present HWM facilities. It is also the date used to retrieve the data (from September 30, 1994, to April 1, 1996)

- Label/waste type (Hazardous, Non-hazardous, Radioactive-LLW, Radioactive-TRU, Mixed-LLW, Mixed-TRU)—This is a waste type description.

- Waste description—This is a freeform field for the description of the waste. This section will refer to it as the "item description." It was used to determine what treatment unit group is used to treat the waste.

- Hazardous constituents—This field contains the hazardous constituent name(s).

- Quantity per item—This field includes both the amount of waste for every item on a requisition. The measurement unit in which the amount was reported is given in an adjacent field.

- Constituent upper quantity—This field gives the generator-specified concentration or mass of each constituent in the waste item. Units of concentration or mass are reported in an adjacent field.

- Radiological data—Several fields are dedicated to specifying the radionuclides, quantities of radionuclides, and quantity units for each item of each requisition.

- Waste form—This states if the waste is a solid, sludge, liquid, or gas.

- Form Code—This is the "B" (i.e., B206) code found for waste types in the biennial report to the Department of Toxic Substances Control (DTSC).

- EPA Number—This is the "U," "P," "K," "F," or "D" code found for waste types in the biennial report to the DTSC.

- DTSC Number—This is the 3-digit number required for manifests.

III.2.1.3 Review of TWMS Query Results

The TWMS database queries resulted in the extraction of a total of 12,389 waste records, each corresponding to a single item of waste received at HWM facilities. The number of containers associated with this waste would be smaller because a single container of waste may contain several items.

After retrieving the data from the TWMS database, the individual data sets for each treatment unit were scanned to determine if there were waste records that seemed to be obviously assigned to incorrect units. The large size of the data sets prohibited a record-by-record review. Some data were removed from the data sets based on waste descriptions that did not fit the unit operations. Most of these records were assigned to other more appropriate units, unless it was determined that they represented waste that would not be treated in the units described in this Health Risk Assessment (HRA); for example, wastes that are shipped off site for treatment and disposal. Reassignments changed the characteristics of some of the waste streams defined previously by the extraction criteria (**Table III-1**). For example, mercury lamps originally were extracted into the data set for the Solidification System. However, these lamps will not be treated in that unit but are, and will be, decontaminated and sent off site for disposal. Therefore, waste items showing these lamps were removed from the data set for the Solidification System and added to the data set for the Size Reduction Unit, where decontamination takes place (**Section II.5.1.2**). Because these lamps are classified as hazardous waste, rather than radioactive or mixed, the Size Reduction Unit data set now includes hazardous waste items in addition to radioactive and mixed waste items.

The criteria for the TWMS database searches that were conducted to develop representative waste streams for the DWTF treatment units were described in **Section III.1.1.2**. To determine the comprehensiveness of the resulting data sets with respect to wastes handled at LLNL, a comparison was made between these data sets and the total inventory of waste in HWM facilities on March 29, 1996.

On March 29, 1996, there were a total of 11,414 waste items in inventory in HWM facilities, based upon the results of a physical inventory. Of these waste items, 8,662 (or approximately 76%) corresponded to waste records found using the TWMS search criteria. The remaining 24% were not included in the data sets derived for this assessment for two reasons. First, most of the excluded items did not fit the search criteria and, thus, are not likely waste that will be treated in the DWTF or the Area 612 Facility considered in this assessment. Second, a smaller portion (less than 10%) were missed in the database extractions because a waste form designation was missing from the waste item record in the database. (In the time since the extractions were made for this assessment, this omission has been corrected in the database.)

The number (12,389) of waste items in the data sets used in this assessment exceeds the number of waste items found in the March 29, 1996, physical inventory by approximately 9%. The explanation for this discrepancy is that many of the waste items identified in the data sets have been shipped off site for treatment and/or disposal and, therefore, were not present during the March 19, 1996, inventory.

Based on this review of TWMS data sets, and the reconciliation of the number of waste items included in these data sets with the number of waste items found in a physical inventory on March 29, 1996, we considered the data sets to be a very comprehensive representation of the waste that may be handled in the DWTF or the Area 612 Size Reduction Unit and Waste Transfer Area as described in LLNL's 1996 Part B Application.

III.2.2   *Waste Quantities*

The quantities of waste destined for each of the DWTF and the Area 612 Facility units from which emissions are considered credible were calculated from the data extracted from the TWMS database. The mass or volume of each waste item is required in order to derive estimates of total constituent mass (**Section III.1.3**). The summed volume or mass of all waste items for each unit is necessary to calculate scaling factors. Scaling factors ultimately allow the calculation of risk based on expected operational capacity of each unit.

The total quantity of waste characterized for each treatment unit is listed in **Table III-2**. These quantities were calculated from the records extracted from the database by converting reported item quantities (listed in **Appendix A** of **Volume 2**) to consistent units of mass (kilograms) and summing. For the Tank Farm, waste quantities from the 1995 HRA (McDowell-Boyer *et al.*, 1995) were used. Expected operational capacities for each unit of concern are also shown in **Table III-2**, as are the scaling factors derived for each unit. The scaling factors were calculated by dividing the expected operational capacities by the actual quantity of waste characterized. A scaling factor of less than one indicates that the mass of waste characterized by constituents exceeded the maximum mass of waste expected to be treated annually.

III.2.3   *Waste Composition*

Knowledge of the composition of the representative waste streams contained in the data sets described in **Section III.2.1.2** is necessary to the assessment of potential risk from the DWTF and associated facilities because risk is a chemical- and radionuclide-dependent quantity. Therefore, each of the waste items contained in the data sets that were developed was analyzed in terms of individual constituent quantities. This analysis required that chemical and radionuclide names be standardized and that quantities be converted to those with consistent units. Chemical names and waste quantities are listed in the database according to the waste generator's chosen conventions. Conventions for naming constituents and quantities vary between generators; thus, standardized conventions were necessarily adopted for this Health Risk Assessment.

For chemical names, the naming convention adopted is consistent with the C*ondensed Chemical Dictionary* (Hawley, 1981). However, many chemicals were not listed in this reference. For these chemicals, the eleventh edition of *The Merck Index* (Budvari, 1989) and the 1995/1996 *Lancaster Catalog* (Lancaster, 1995) was also consulted. For a small number of chemicals, primarily biological substances, standardized names were obtained from *Stedman's Illustrated Medical Dictionary* (Stedman, 1982). For chemicals not found in any of these resources, a category called "non-specific" was created, and these chemicals were assigned to this category. **Appendix B** tables in **Volume 2** list the standardized name, or the "non-specific" designation, assigned to each chemical identified in the TWMS-based data sets.

The constituent name listed in the database is not always specific for a chemical, but rather is indicative of a category of compounds. Oil and diesel are variable mixtures of petroleum hydrocarbons which appear as constituents on HWM Division waste requisitions. Because quantitative toxicity data are not available for these mixtures, it was necessary to consider their specific chemical constituents.

The term "oil" may represent a wide range of substances with very different properties. The four most commonly used oils at LLNL are Vactra 2, Mobil DTE #26, Mobil DTE #25, and Mobil DTE #24. According to Stoker and Seager (1976), most hydrocarbons that are highly volatile at normal atmospheric temperature and, thus, are most important in air pollution, are relatively simple compounds containing 12 or fewer carbon atoms per molecule. Therefore, laboratory headspace analyses of these oils were completed to quantify the fraction of volatile hydrocarbon compounds with fewer than 12 carbon atoms per molecule as well as to identify volatile aromatic and halocarbon constituents using the U.S. Environmental Protection Agency (EPA) Method 8021 (LLNL, 1995). The EPA Method 8021 analytical results showed 2-mg/kg benzene in Mobil DTE #26; and 2-mg/kg ethylbenzene and 10-mg/kg total xylenes in the Vactra 2. None of the headspace analyses for these oils detected compounds with fewer than 10 carbon atoms per molecule, based on the headspace method detection limit of 20 mg/kg. One headspace analysis detected compounds with fewer than 12 carbon atoms at a concentration of 150 mg/kg, based on the headspace method detection limit of 20 mg/kg. The compound(s) making up the 150-mg/kg concentration were then assumed to be naphthalene. Based on this information, we assumed the term "oil" to be a constituent that is composed of 2-mg/kg benzene, 2-mg/kg ethylbenzene, 10-mg/kg total xylenes, and 150-mg/kg naphthalene (a C-10 compound).

The term "diesel" was replaced by the constituents benzene, toluene, and xylenes (all isomers), based on the following information. Quantitative analyses of diesel by LLNL (EPA Methods 8021 and 8270) identified toluene (80 mg/kg) and xylenes (all isomers, 730 mg/kg) as the only constituents having 12 or fewer carbon atoms above the 70-mg/kg limit of detection (LOD) (LLNL, 1995). It was assumed that these analytical data are representative of diesel treated or handled by HWM Division at LLNL. However, the carcinogen benzene has also been reported as a potential constituent of diesel (California Regional Water Quality Control Board [RWQCB], 1990). To account for this possibility, we assumed that diesel treated or handled by HWM Division would contain benzene in an amount equal to the analytical LOD (EPA Method 8021) of 70 mg/kg. Accordingly, we assumed benzene is present in diesel at 70 mg/kg, toluene at 80 mg/kg, and xylenes (all isomers) at 730 mg/kg.

The nonradioactive constituents contained in each data set are listed alphabetically by standardized name in **Volume 2**, **Appendix B**. A separate table is devoted to each treatment unit. The original value and units of constituent quantity are given for each waste item of each data set in this appendix as well as the constituent quantity converted to units of kilograms and the conversion factor used. Constituent quantities are reported in a variety of units, including units of mass and units of concentration. When concentration units were specified, it was necessary to multiply the concentration by the mass of the waste item to achieve conversion to units of mass. When necessary (i.e., when concentrations were reported in mass per unit volume), the density of liquid wastes were assumed to be 1.0 kg/L. The total mass of each constituent is calculated for each treatment unit by summing the quantities for each waste item. In **Volume 2** of this document, these sums appear in **Appendix B** tables and are summarized in **Appendix C** for each treatment unit. **Appendix C** tables also contain the "scaled total mass of chemical," which is the summed mass multiplied by the appropriate scaling factor from **Table III-2**. The scaled mass represents the mass of each constituent assumed to be typical of the waste stream for each treatment unit at the operational capacity of that unit.

For radionuclides, a set of tables corresponding to those for chemicals in **Appendix B** is given in **Appendix D** of **Volume 2**. With a few exceptions, radionuclide names are standardized in the TWMS database. The exceptions of importance to this assessment were the "NAT-U" and "MFP" designations.

The term "NAT-U" was used infrequently by some generators to indicate natural uranium. In this assessment, natural uranium was assumed to be U-238; therefore, NAT-U was labeled U-238. Although natural uranium contains a small amount of U-235 (0.7%) and, thus, has a specific activity slightly greater than that for U-238, the dose factors for U-238 and U-235 are very similar. The total activity of natural uranium in the data sets for any unit was less than 0.1% of the activity of U-238; and, thus, the treatment of natural uranium as U-238 added a negligible error to the results.

The "MFP" designation was used by some generators to indicate mixed fission products. While thermal fission yields approximately 200 fission products with mass numbers ranging from 72 to 158, there are maxima in the fission-product yield curves that occur at mass numbers corresponding to Sr-90 and Cs-137, indicating that these two radionuclides are more abundant than most others. The radionuclide Sr-90 was chosen to represent the category "MFP" because it

has a significantly larger dose factor than that for Cs-137; and, thus, its selection will tend to maximize risk calculations.

Radionuclide quantities are reported in **Volume 2**, **Appendix D** in units of radioactivity, or Ci. When radionuclide quantities were reported in units of mass, rather than activity, conversions to activity were accomplished using published values of specific activity (Browne and Firestone, 1986). For two radionuclides, U-238 and Th-232, specific activities were not available in the literature consulted. In these cases, specific activity was calculated from:

$$\text{Specific activity} \frac{3578 \times 10^3}{(T_{1/2})(\text{atomic mass})},$$

where $T_{1/2}$ is the radionuclide half-life, in years (U.S. Department of Health, Education, and Welfare [HEW], 1970). Radionuclide half-lives were also obtained from Browne and Firestone (1986). Summarized total activities (in Ci) of radionuclides in each treatment unit are given in **Volume 2**, **Appendix E**. As with chemical constituent quantities, the total radionuclide activities are also scaled to the operational capacity of each unit in **Appendix E**, thus representing the total activity of each radionuclide assumed to be typical of the waste stream for each treatment unit at the operational capacity of that unit.

The waste streams described by **Appendix A** through **Appendix E** in **Volume 2** do not include the waste streams destined for the Tank Farm and associated units (Blending Station and Evaporator) or waste streams destined only for waste transfer at the Area 612 Facility and the DWTF. Representative waste streams were developed for these units and facilities in the 1995 HRA (McDowell-Boyer *et al.*, 1995), as noted earlier, and are used without modification in this assessment. Scaling factors were changed, however, for the Tank Farm (from 5 to 6.5) to account for the increased operational capacity of that unit in the DWTF over that of its precursor at Area 514.

III.3 Emission Rates

Representative waste streams were characterized according to the methods described in the previous section. Results of this characterization are reported in **Appendix A** through **Appendix E** of **Volume 2** of this report. In this section, methods for calculating emission rates to the atmosphere from waste handling and treatment activities at the DWTF, the Building 612 Size Reduction Unit, and the Area 612 Facility are addressed.

Two types of emission rates were required for this assessment. The estimated annual release of radioactive and nonradioactive constituents to the atmosphere is the first type. The second type is applicable to chemicals that potentially pose an acute inhalation hazard. For these chemicals, maximum hourly emissions were calculated.

In order to calculate emission rates, modes of release from each of the treatment units and the presence of abatement devices (e.g., activated carbon, HEPA filters, etc.) were considered. Emission factors were used to represent the fractional release of waste constituents from each treatment unit, and abatement factors were used to represent the fraction of constituents released

from the treatment unit to the atmosphere. Chemical- and radionuclide-specific emission rates were calculated from:

Emission Rate = Constituent Quantity × Emission Factor × Abatement Factor

where the constituent quantity is the scaled mass of each constituent, and the emission; and abatement factors are dependent on the physical form of the chemical constituents, the physical form of the waste streams, and the design features of the treatment unit.

III.3.1 Emission Factors

Emission factors are a function of the physical form of waste streams (i.e., liquid, solid, or sludge) and the physical/chemical properties of constituents within these waste streams. Volatile compounds and gases can be expected to be released at some rate from liquids, solids, and sludge. Release of nonvolatile compounds from liquids and sludge are expected to be negligible. However, releases of nonvolatile compounds from solids, as fine particulates, must be considered.

The classification of the various chemicals encountered in the TWMS data sets according to physical form was accomplished by reference to the sources which are cited in **Table K-1** of **Appendix K**, **Volume 2**. For chemicals with unique standardized chemical names (i.e., not labeled "non-specific," **Section III.1.3**), the physical form categories of L_1, L_2, S, and G were assigned. All nonradioactive constituents were assigned to one of these categories except for mercury. A separate category for mercury was created because emissions of this constituent were considered separately. Constituents falling into the L_1 category are those compounds that are liquid in form and considered nonvolatile, having vapor pressures less than 0.133 Pa (0.001-mm Hg). These L_1 compounds are assumed to be adsorbed to particulate material in solid waste streams. Volatile compounds, designated as L_2 compounds, are defined as those constituents considered liquid in form with vapor pressures equal to or exceeding 0.133 Pa (0.001-mm Hg) at 20°C, consistent with California Environmental Protection Agency's (CAL/EPA) *Preliminary Endangerment Assessment (PEA) Guidance Manual* (1994). Vapor pressures used to evaluate the volatility of L_1 and L_2 compounds identified in the TWMS data sets are listed in **Table K--1**, **Appendix K**, **Volume 2**. The L_2 designation applies to volatile compounds in nonaqueous waste streams. For aqueous wastes destined for the Tank Farm and associated units, and the Area 612 Facility and the DWTF waste transfer areas, constituents of waste streams having Henry's constants greater than or equal to 1.0 Pa-m^3/mol are considered volatile. (A more detailed discussion of this criteria and the values of Henry's constants used are available in the 1995 HRA [McDowell-Boyer *et al.*, 1995]).

The last two designations of physical form for constituents of waste streams destined for the DWTF or the Area 612 Facility units described here are the S and G categories. Constituents of waste considered in solid form are given the designation of S; constituents considered gaseous in form are given the designation of G.

Specific information about physical form was not found for some compounds with unique standardized chemical names. These compounds were assumed to be volatile and were assigned to the L_2 category, thus maximizing the calculated potential emission of these compounds. A

separate protocol was developed for compounds labeled "non-specific," comprised of compounds for which standardized chemical names could not be identified (**Section III.1.3**). It was assumed that the distribution of physical forms of the identifiable compounds is similar to the distribution of physical forms within the group of "non-specific" chemicals. In other words, the fraction of L_1, L_2, S, and G designations characteristic of the known group are assumed to characterize the "non-specific" group.

The manner in which radionuclide constituents are recorded in the TWMS database generally precludes compound-specific analysis. Only radionuclide names are provided in the nuclide column, and seldom is the chemical form given even in the waste description field. Radionuclides were grouped into the following categories defining physical/chemical form:

- Noble gases—as a volatile gas in any waste stream

- C-14—either as a particulate in most solid wastes, or as a dissolved constituent of liquid wastes

- H-3—associated with water (HTO) in either liquid or solid wastes

- Other radionuclides—dissolved nonvolatile particulates in liquid wastes, or particulate contamination in solid wastes.

In this Health Risk Assessment, several simplifying assumptions were made to estimate emission factors for the various units. Simplifications were necessary because many of the waste streams and handling procedures are poorly defined in terms of characteristics important to analysis of release rates. For example, the portion of debris waste that is in a small particulate form and, thus, resuspendable is undefined. Furthermore, how long this waste might be exposed to the atmosphere during loading of the shredder/chopper or debris washer is not clearly defined. A discussion of these simplifying assumptions is provided below, according to the type of emission distinguished in this assessment (i.e., volatile, particulate, mercury, and radionuclide).

III.3.1.1 Emissions of Volatile Chemicals

Emissions of volatile compounds (L_2) and gases (G) may occur from waste streams that are either liquid, solid, or sludge. In this assessment, it is assumed that 100% of volatile organic compounds and gases present in all waste streams, except those handled in the waste transfer areas of the Area 612 Facility and the DWTF, are released to the atmosphere. For waste transfer activities, a loading loss equation provided by the EPA, and described in the 1995 HRA (McDowell-Boyer *et al.*, 1995) was used. For volatile inorganic acids, 100% emissions are assumed for all units except the Solidification System. Concentrated acids in the Solidification System waste stream (pH<2) will be neutralized prior to solidification. Neutralization and other physical/chemical processes occurring in the solidification process should result in no more than 5% of the acids and bases in the waste stream being released as air emissions; thus, an emission factor of 0.05 was assumed for volatile inorganic acids. The assumption of 100% loss of volatile organic compounds for other activities will overestimate releases from most units. For example, fugitive emissions from waste solvent reclamation processes, which approximate emissions from

the Filtration Module when concentrated solvents are loaded into the feed/mixing vessel, are characterized by emission factors on the order of 4.0E-4, according to the EPA (1995).

III.3.1.2 Emissions of Particulate Chemicals

Emissions of chemicals in particulate form (S and L_1) may occur when handling procedures are such that the more finely divided particles in the waste become suspended in air. Transferring waste from storage containers to treatment units and decontaminating waste items in the Size Reduction Unit are the most likely procedures to cause suspension of small particulates. Particulate emissions are considered negligible for liquid wastes in this assessment; transfer of liquids between containers is generally accomplished through closed piping, thus limiting emissions during this activity. Resuspension of particulates from liquids is generally two orders of magnitude lower than resuspension of particulates from solid surfaces (DOE, 1993). Thus, the emission factor for particulate chemicals in liquid waste streams is assumed to be zero (**Table III-3**).

The units treating solid waste from which particulate emissions may occur are the Shredder/Chopper, the Size Reduction Unit, the Debris Washer, the Solidification System, the Pressure Reactor, and the Water Reactor. Entrainment of fine particulates that are, or are adsorbed to, chemical contaminants may lead to emission of particulate chemicals from the units. Entrainment may occur when waste is dropped into a hopper, and dust present in the waste is suspended, or when disturbance of the surface contamination on equipment during decontamination causes resuspension. Because blasting and washing will involve liquids or slurries contacting the contaminated equipment, particulate emissions will be controlled to some extent, although pertinent data were not found with which to quantify this source of particulates. In lieu of appropriate data, it was assumed that emissions from decontamination would be on the same order of magnitude as those from loading operations.

The EPA-approved emission factor for processing of solid forms of radionuclides at temperatures less than 100°C is 1.0E-6; for powders, an emission factor of 1.0E-3 is approved (EPA, 1989). For powders, the EPA cites data showing a range in emission factors of 1.0E-6 to 1.0E-3 for various activities. This suggests that the emission factor for surface contamination associated with combustible (i.e., debris) or noncombustible waste (i.e., equipment, containers), whether radioactive or nonradioactive, probably falls within the range of 1.0E-6 to 1.0E-3. A DOE handbook (1993) that provides emission factors for use in evaluating worst-case accident scenarios for fuel cycle facilities was consulted. This DOE handbook recommends use of emission factors for aerodynamic entrainment of, or free-fall of, powders in lieu of data pertinent to the corresponding processes involving combustible or noncombustible materials. For powders, the DOE handbook provides a bounding resuspension rate of 4.0E-5/hr, with a respirable fraction of 1.0, for normal process facility ventilation flow. A median emission factor of 3.0E-4, with a respirable fraction of 0.5, is given for free-fall of powders from a fall distance of less than 3 meters.

The waste treatment processes proposed for the DWTF do not suggest that waste will be susceptible to aerodynamic entrainment processes for periods of time greatly exceeding one hour; therefore, the free-fall emission factor appears to bound the particulate emission process. Solids in the DWTF are extremely diverse, ranging from soils to debris to glassware and

gloveboxes. It is reasonable to assume that a small portion of this waste may be in powder form (e.g., small soil particles, dust). Assuming that 20% is in powder form, an emission factor of 3.0E-5 (3.0E-4 × 0.5 × 0.20) is calculated. This value falls within the emission factor range of 1.0E-6 for solids and 1.0E-3 for powders that is approved by EPA and, thus, was used in this assessment for particulates emitted from solid wastes (**Table III-3**).

III.3.1.3 Emissions of Mercury

Representative waste streams containing mercury include those destined for the Debris Washer, the Shredder/Chopper, the Size Reduction Unit, the Solidification System, the Amalgamation Unit, the Filtration Module, the Tank Farm and associated units, and for waste transfer at the Area 612 Facility and the DWTF. Wastes that list mercury as a constituent are highly variable and include such items as contaminated HEPA filters, laboratory "trash," sludge, organic solutions, soil, air ducting, vacuum pumps, oil, and spent mercury lamps (i.e., fluorescent tubes) in addition to the aqueous wastes treated in the Filtration Module or the Tank Farm, and/or handled in the waste transfer areas. In this assessment, it was assumed that mercury, when present, is present as a liquid, as this is the form of mercury at ambient temperatures.

The EPA-approved, National Emissions Standards for Hazardous Air Pollutants (NESHAPs) emission factor of 1.0E-3 for liquids (EPA, 1989) was assumed for emissions of mercury contained in wastes destined for the Debris Washer, the Shredder/Chopper, the Size Reduction Unit, and the Solidification System (**Table III-3**). A more detailed evaluation of mercury emissions was not possible due to the uncertainties associated with the physical and chemical form of mercury in the variable waste streams.

For the Amalgamation Unit, where mercury is more likely to be in elemental form and, thus, more easily recoverable, an estimate of the evaporation rate of mercury was made. Mercury emissions from a small pool of mercury exposed to the atmosphere were estimated from a simplified equation provided by Tinsley (1979):

$$Q = \beta p \left(\frac{M}{2\pi RT} \right)^{1/2},$$

where:

Q = evaporative loss rate of a pure compound, in g/cm^2-s,
β = a factor that accounts for the evaporation into air, rather than a vacuum,
M = molecular weight of compound,
P = vapor pressure of the compound at T, g/cm-s^2,
R = gas constant, 0.082 L-atm/mol-°K, and
T = temperature, in °K.

The average value of β for 18 compounds with molecular weights up to 190 is reported to be relatively constant at 1.98E-5 (Tinsley, 1979). Because the molecular weight of mercury (201 g/mole) is not much greater than 190, the value of β is assumed to be 1.98E-5 in this application. Assuming an average temperature of 293°K (20°C), and a vapor pressure of mercury

of 0.001691-mm Hg (or 2.25 g/cm-s^2) at this temperature, an evaporative loss rate of 1.6.0E-9 g/cm^2-s was calculated. In the Amalgamation Unit, mercury may be exposed to the air when it is transferred from small containers to the reactor. Assuming a 6-in.-(15.2-cm-) diameter exposure area (corresponding to the approximate diameter of the opening of the small containers), an evaporative loss of about 3.0E-7 g/s (or 1.0E-3 g/h) of mercury was calculated. Assuming that the Amalgamation Unit is operated 365 days a year, and that mercury is exposed to the air one hour per day (which is undoubtedly an overestimate of the time necessary to accomplish transfers to the reactor), the total annual mercury released from this unit is estimated to be approximately 0.4 g. In **Appendix C** of **Volume 2**, the total annual quantity of mercury destined for treatment in the Amalgamation Unit, at operational capacity, is 528 kg. A fractional release, calculated by dividing the annual release rate by the annual quantity treated, can be estimated following this procedure to be 7.0E-7. However, this computational method for fractional release is sensitive to the quantity of mercury assumed to be treated, yet the total release may not be equally sensitive. In other words, amalgamation of a smaller quantity of mercury does not necessarily imply a correspondingly smaller time of exposure of mercury to air. Therefore, it was assumed that the emission factor for mercury from the amalgamation unit was 1.0E-3, consistent with the NESHAPs factor for liquids, which is believed to provide an upper-bound estimate of mercury releases from the Amalgamation Unit (**Table III-3**).

For aqueous waste streams that are treated in the Filtration Module, the Tank Farm and associated units, or transferred at the Area 612 Facility or the DWTF, 100% of the mercury was assumed to be released (McDowell-Boyer *et al.*, 1995). This assumption is consistent with the manner in which all volatile compounds were treated in the 1995 HRA (McDowell-Boyer *et al.*, 1995).

III.3.1.4 Emissions of Radionuclides

Emissions of volatile and gaseous forms of radionuclides may occur from both liquid and solid waste streams destined for treatment in the DWTF and associated Area 612 Facility units. Noble gases, such as Kr-85, are essentially nonreactive and were assumed to be 100% volatilized from any waste stream; thus, an emission factor of 1 was used (**Table III-3**).

Carbon-14 may exist in either a solid, dissolved, or volatile phase (as $^{14}CO_2$). Descriptions of waste containing this radionuclide most often did not specify the physical form of C-14. In solid waste except for those destined for the Debris Washer, it was assumed that C-14 was present as a solid. However, because the possibility exists that a small, but not readily quantifiable, portion of the C-14 may have partitioned into the gas phase during storage or handling, it was assumed that the C-14 in solid waste was all present as a powder, and an emission factor of 1.0E-3 was assumed (**Table III-3**). This EPA-approved, upper-bound emission factor for powders (EPA, 1989) is about 33 times higher than that assumed for other particulates in this assessment and is believed to bound the emissions of C-14 from most solid wastes. One exception to this is the C-14 that may be sent to the Debris Washer for treatment. Because strong acids may be used in this unit to treat wastes, and these strong acids have the potential for liberating significant quantities of CO_2 when carbon is present, an emission factor of 1 was assumed for any C-14 listed in the data set for the Debris Washer (**Table III-3**). For liquid wastes, an emission factor of 1.0E-3 was

assumed for C-14 (**Table III-3**). This factor is consistent with that used by LLNL for C-14 in demonstrating compliance with NESHAPs (40 CFR Part 61, Subpart H) (LLNL, 1995).

The physical/chemical form of tritium is rarely stated in the TWMS-based data sets. It is expected, however, that tritium (H-3) in liquid waste streams will largely exist as tritiated water at room temperature. Likewise, with solid wastes, tritium that exists as surface contamination is assumed to be associated with water. The dose factor for tritiated water is about four orders of magnitude higher than that for elemental tritium; and, thus, this assumption is bounding. Therefore, an emission factor of 1.0E-3, consistent with the LLNL NESHAPs compliance demonstrations (LLNL, 1995), was assumed for H-3 present in waste.

For radionuclides in solid waste other than noble gases, H-3, and C-14, an emission factor of 3.0E-5 was assumed. This is consistent with the factor assumed for particulate chemicals and is justified in **Section III.2.1.2**. For liquid wastes, dissolved radionuclides other than noble gases, H-3 and C-14, are not assumed to be emitted from the waste, consistent with the approach taken for particulate chemicals in liquid waste streams.

III.3.2   Abatement Factors

Abatement devices are designed for the equipment to be used in Building 695 and at the Area 612 Facility to treat mixed and hazardous waste to control emissions. Devices controlling emissions from units that will operate in Building 695 are shown in **Figure II-8** of **Section II** and include individual HEPA filters for most units, as well as carbon canisters. In addition, the general building ventilation includes a building HEPA filter. At Building 612, at least two HEPA filters remove particulates from air to be exhausted from the Size Reduction Unit. Emissions from the waste transfer operations at the Area 612 Facility and Building 695 are not abated.

In order to quantify the efficiency of emission controls, abatement factors were assigned to the various control devices used. For single-stage HEPA filters, an abatement factor of 1.0E-2 (**Table III-4**) was assigned, indicating a 99% efficiency of these filters for removing particulate chemicals and particulate radionuclides. This value is consistent with that recommended for use by the EPA in demonstrating compliance with NESHAPs. It is recognized, however, that HEPA filters are rated at a much higher efficiency (99.97%), when properly maintained. For two-stage HEPA filters (e.g., a single-stage HEPA on the unit, plus the building HEPA filter), an abatement factor of 1.0E-4 (**Table III-4**) was assumed.

The efficiency of carbon canisters for attenuating emissions of volatile organic compounds varies widely according to the compound. Some compounds are readily adsorbed, and some are poorly adsorbed. For this assessment, an abatement factor of 5.0E-2 (**Table III-4**) is assumed for all volatile organic compounds. This abatement factor corresponds to a 95% carbon canister efficiency in removing volatile organics from airborne effluents from the treatment units and is consistent with the Resource Conservation and Recovery Act (RCRA) Subpart CC requirement (or CC Rule) that organic vapors be reduced by at least 95% by weight. The CC Rule applies to most of the treatment units in the DWTF. It is, however, recognized that some compounds will be controlled with an efficiency of greater than 95%, and some will be controlled with an efficiency of less than 95%, and an attempt to distinguish the variable control was not addressed in this assessment.

Acid scrubbers are present as abatement devices for the Debris Washer, the Tank Farm and associated units, the Uranium Bleaching Unit, the Water Reactor, the Pressure Reactor, and the Amalgamation Unit. The EPA, in its AP-42 compilation of emission factors, cites control efficiencies for scrubbers used in abatement of phosphoric acid, nitric acid, hydrochloric acid, and hydrofluoric acid of greater than 97.5%, 99%, 99%, and 89%, respectively (EPA, 1995). Based on this information, a control efficiency of 95% was assumed in this assessment, such that an abatement factor for volatile inorganic acid compounds potentially emitted from units with acid scrubbers is assumed to be 5.0E-2 (**Table III-4**).

Chemicals and radionuclides for which abatement devices are assumed inefficient are assigned an abatement factor of 1.0. Included in this category are H-3, C-14, and mercury.

III.3.3   *Estimated Annual Emissions*

Estimated annual emissions for the DWTF and the Area 612 Facility treatment and handling units considered sources of emissions in this assessment were calculated using the waste constituent quantities, emission factors, and abatement factors discussed in the preceding paragraphs. Annual emissions were calculated for all chemical and radioactive constituents listed in **Appendix C** and **Appendix E** in **Volume 2** of this health risk assessment. Multiplication of constituent quantities scaled to the annual operational capacity of each unit, by unit-specific emission and abatement factors results in constituent-unit-specific emission rates that are expressed in kg/y for nonradioactive constituents (**"Table 1," Volume 2**) and Ci/y for radioactive constituents (**Appendix E**).

These emission rates, by virtue of their reliance on representative waste streams developed for this assessment, are considered *qualitatively* representative of emission rates that may occur when all units are operated at full capacity throughout a year. However, because of the many assumptions that were made that tend to maximize emissions in light of uncertainties in factors affecting emissions, the emission rates are considered upper-bound estimates. The assumption of 100% volatilization of most volatile organic compounds and mercury is one of the more significant assumptions that tends to maximize these estimates. Assuming particulates are retained in HEPA filters with an efficiency of only 99%, when ratings of these filters suggests a much higher efficiency (99.97%), is likely to lead to overestimates of the emissions of particulates. A further bounding assumption that is made in applying these emission rates toward estimating doses is that the waste streams are independent for each treatment unit. Actually, the manner in which data sets were derived (**Section III.1.1.2**) resulted in some overlap of waste records between treatment units. For example, many waste records designated for the Shredder/Chopper were also designated for the Debris Washer *and* the Size Reduction Unit. No effort was made to determine which unit would result in the highest emission; instead, emissions were calculated assuming these overlapping waste records would be treated by each of the units. In other words, emissions may in some cases represent a double- or triple-accounting of a particular waste record.

The emission rates provided in **"Table 1,"** and **Appendix E** in **Volume 2** are used in **Sections VII** and **VIII** of this risk assessment to evaluate potential dose and risk from exposures resulting from emissions from the Building 695 and the Area 612 Facility stacks and area sources.

Because the emission rates are considered upper-bound estimates, the calculated doses and risks based on these emissions will also be upper-bound estimates.

III.3.4   *Estimated Maximum Hourly Emissions*

Chemicals of concern for the maximum hourly emissions are those that pose an acute exposure hazard. The HRA (McDowell-Boyer *et al.*, 1995) described the identification of these chemicals for the Tank Farm and for the Area 612 Waste Transfer Area. For the present assessment of potential acute health effects from the Tank Farm, the maximum hourly emission rate of chemicals were increased to account for the increase in the planned annual treatment of aqueous waste from 250,000 gal (McDowell-Boyer *et al.*, 1995) to 326,000 gal (1.23E+6 kg) (**Table III-2**). The identity and estimated release rates of chemicals from the Area 612 Waste Transfer Area are assumed to be the same as originally presented in the HRA (McDowell-Boyer *et al.*, 1995). Because activities at the Building 695 (DWTF) Waste Transfer Area are expected to be equivalent to those at the Area 612 Waste Transfer Area, the chemicals of concern and emission rates of these chemicals evaluated for the two areas are identical.

For the new waste treatment units at the DWTF (Centrifuge, Filtration Module, Uranium Bleaching unit, Amalgamation unit, Debris Washer/Dryer, Pressure Reactor, Water Reactor, Shredder/Chopper, and Solidification System) and the Size Reduction Unit at Building 612, hypothetical maximum hourly emission data sets were developed. For each treatment unit, the list of unique chemicals associated with the waste requisitions designated for that unit (**Appendix B** in **Volume 2**) were reviewed, and all chemicals that have a one-hour recommended exposure limit (REL) developed by the State of California (California Air Pollution Control Officers Association [CAPCOA], 1993; CAL/EPA/Office of Environmental Health Hazards Assessment [OEHHA], 1994) were identified. For each of these chemicals in each treatment unit, the calculated maximum mass from the set of all requisition-specific masses was selected. All chemical maxima were combined to form a single, hypothetical waste stream, under the assumption that all chemical maxima identified in this manner would be treated simultaneously in a specific unit, with all emissions resulting from that treatment occurring within a one-hour period. Emission factors and abatement factors were applied depending on the assigned physical form of each chemical and the abatement devices associated with each treatment unit (**Section III.2.1** and **Section III.2.2**).

Maximum hourly capacities of each waste treatment unit were calculated by dividing the daily capacity of the unit (**Table III-5**) by eight, based on an assumed daily operation time of eight hours. Maximum hourly waste streams were scaled to reflect capacity (limitations) only for those treatment units where the total mass of waste associated with the maximum hourly chemical data set exceeded the hourly capacity of the treatment unit. The chemicals evaluated for maximum hourly emissions are listed in **Appendix B′** of **Volume 2**, and the maximum hourly release rates are provided in **Appendix H** (40 CFR Part 61, Subpart H) of **Volume 2** for each treatment unit.

III.4   References

Browne, Edgardo, and Richard B. Firestone. 1986. *Table of Radioactive Isotopes*. Virginia S. Shirley, ed., John Wiley & Sons, New York, NY.

Budvari, S., ed. 1989. *The Merck Index, An Encyclopedia of Chemicals, Drugs, and Biologicals*. Eleventh Edition. Merck and Co., Rahway, NJ.

California Air Pollution Control Officers Association (CAPCOA). 1993. *Air Toxics "Hot Spots" Program, Revised 1992 Risk Assessment Guidelines*. Toxics Committee of the California Air Pollution Control Officers Association, in consultation with the Air Toxicology Unit, Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment, and the Special Projects Section, Toxic Air Contaminant Identification Branch, Air Resources Board. Sacramento. October.

California Environmental Protection Agency, Department of Toxic Substances Control (CAL/EPA). 1994. *Preliminary Endangerment Assessment (PEA) Guidance Manual (A guidance manual for evaluating hazardous substances release sites).* California Environmental Protection Agency, Department of Toxic Substances Control, Sacramento, January.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1994. *Air Toxics "Hot Spots "Program Risk Assessment Guidelines: Part 1, Evaluation of Acute Non-Cancer Health Effects, Draft for Public Comment.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, December.

Hawley, Gessner, G. 1981. *The Condensed Chemical Dictionary*. Van Nostrand Reinhold Company, New York.

Lancaster, 1995.

Lawrence Livermore National Laboratory (LLNL). 1995. *Data Supporting the 1995 Health Risk Assessment for Hazardous and Mixed Waste Management (HWM) Facilities at LLNL.* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-AR-122091.

Lawrence Livermore National Laboratory (LLNL). 1996. *Resource Conservation and Recovery Act Part B Permit Application, Hazardous Waste Treatment and Storage Facilities*. Lawrence Livermore National Laboratory, Livermore, CA.

McDowell-Boyer, L.; J. Daniels; G. Gallegos; F. Gouveia; L. Hall; G. May; T. Kato; J. Huang; and A. Dennis. 1995. *Health Risk Assessment for Hazardous and Mixed Waste Management Units at Lawrence Livermore National Laboratory, 1995*. (1995 Health Risk Assessment [HRA]). Lawrence Livermore National Laboratory, Livermore, CA, November, UCRL-AR-119482.

Regional Water Quality Control Board (RWQCB). 1990. Regional Water Quality Control Board, Sacramento, CA.

Stedman, Thomas J. 1982. *Stedman's Illustrated Medical Dictionary.* Williams and Wilkins, Baltimore, MD.

Stoker, H. Stephen, and Spencer L. Seager. 1976. *Environmental Chemistry: Air and Water Pollution.* Second Edition. Scott, Foresman and Company, Glenview, IL.

Tinsley, Ian J. 1979. *Chemical Concepts in Pollutant Behavior.* John Wiley & Sons, New York, NY.

U.S. Department of Energy (DOE). 1993. *Recommended Values and Technical Bases for Airborne Release Fractions (ARFs), Airborne Release Rates (ARRs), and Respirable Fractions (RFs) at DOE Non-Reactor Nuclear Facilities.* DOE Handbook, DOE-HDBK-0013-93, U.S. Department of Energy, Washington, D.C., July.

U.S. Department of Health, Education, and Welfare (HEW). 1970. *Radiological Health Handbook.* Revised Edition, U.S. Department of Health, Education, and Welfare, Public Health Service, January.

U.S. Environmental Protection Agency (EPA). 1989. *Background Information Document: Procedures Approved for Demonstrating Compliance with 40 CFR Part 61, Subpart 1.* Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1995. *Compilation of Air Pollutant Emission Factors (AP-42).* U.S. Department of the Interior, Environmental Protection Agency, Research Triangle Park, NC.

III.5   Acronyms

CAL/EPA   California Environmental Protection Agency

CAPCOA   California Air Pollution Control Officers Association

HRA   Health Risk Assessment

DOE   U.S. Department of Energy

DTSC   Department of Toxic Substances Control

DWTF   Decontamination and Waste Treatment Facility

EPA   U.S. Environmental Protection Agency

HEPA   High-efficiency particulate air (filter)

HEW   U.S. Department of Health, Education, and Welfare

HR   Health Risk Assessment

HWM	Hazardous Waste Management
LLNL	Lawrence Livermore National Laboratory
LOD	Limit of Detection
MFP	Mixed fission products
NAT-U	Natural Uranium
NESHAPs	National Emissions Standards for Hazardous Air Pollutants
OEHHA	Office of Environmental Health Hazard
PEA	Preliminary Endangerment Assessment
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit
RWQCB	Regional Water Quality Control Board
TWMS	Total Waste Management System
WDR	Waste Disposal Requisition

Table III-1. TWMS Search Criteria for DWTF Treatment Units; Basis for Preliminary Data Sets

Name of Treatment Unit	Storage Location Criterion	Waste Form and Type Criterion	Form Code Criterion
Amalgamation Unit	Building 614	none	none
Bleaching Unit	Building 513	none	none
Centrifuge Unit	Building 321, 321A, or 321C (Generation)	liquid waste	B201,B202, B203, B204, B205, B206, B207
Debris Washer	Area 612-1, 612-2, 612-5, or Building 612, Room 100	solid waste, radioactive or mixed	none
Filtration Module	none	liquid waste	B201,B202, B203, B204, B205, B206, B207
Pressure Reactor	Building 614	none	none
Shredder/Chopper	Area 612-1, 612-2, 612-5, or Building 612, Room 100	solid waste, radioactive or mixed	none
Size Reduction Unit	Area 612-1, 612-2, 612-5, or Building 612, Room 100	solid waste, radioactive or mixed	none
Solidification System	none	none	B205, B206, B209, B210, B212, B219, B301, B302, B303, B304, B305, B306, B307, B308, B309, B310, B311, B312, B313, B314, B315, B316, B319, B404, B501, B502, B503, B504, B505, B506, B507, B508, B509, B510, B511, B512, B513, B514, B515, B516, B519, B603, B609
Tank Farm	see reference[a]	see reference[a]	see reference[a]
612 Transfer Area	see reference[a]	see reference[a]	see reference[a]
DWTF Transfer Area	see reference[a]	see reference[a]	see reference[a]
Water Reactor	Building 614	none	none

[a] Data sets for these units were derived in the 1995 HRA (McDowell-Boyer *et al.,* 1995).

Table III-2. Operating Capacities and Scaling Factors Assumed for Characterizing DWTF Waste Streams

Name of Treatment Unit	Baseline Annual Operating Capacity (kg/y)	Mass of Waste Characterized for Unit (kg/y)	Scaling Factor[1]
Amalgamation Unit	3.10E+04	6.79E+03	4.6E+00
Bleaching Unit	3.27E+04	4.42E+04	7.4E-01
Centrifuge Unit	2.08E+05	2.02E+04	1.0E+01
Debris Washer	4.09E+04	4.13E+04	9.9E-01
Filtration Module	1.04E+04	2.29E+05	4.5E-02
Pressure Reactor	3.10E+04	6.10E+02	5.1E+01
Shredder/Chopper	1.66E+05	1.03E+05	1.6E+00
Size Reduction Unit	2.27E+05	1.18E+05	1.9E+00
Solidification System	1.04E+05	8.07E+05	1.3E-01
Tank Farm	1.23E+06	1.89E+05	6.5E+00
Area 612 Transfers	see reference[2]	see reference[2]	2.0E+00[2]
DWTF Transfers	see reference[2]	see reference[2]	2.0E+00[2]
Water Reactor	3.10E+04	2.32E+03	1.3E+01

[1] Scaling factor is calculated by dividing the Baseline Annual Operating Capacity by the Mass of Waste Characterized for each unit.

[2] Emissions from the waste transfer operations at Area 612 and the DWTF were not estimated based on waste volumes, but on constituent quantities (McDowell-Boyer *et al.,* 1995); therefore, scaling factors were not based on the ratio of operating capacity to mass of waste characterized. Rather, the scaling factors were assumed to be 2.0 to account for potential increased operations in these areas.

Table III-3.   Emission Factors Assumed for the DWTF and Area 612 Waste Streams and Treatment Units

Form of Waste Treated	Treatment Units	Physical Form of Chemical					Physical Form of Radionuclide		
		L_1 [a]	L_2 [b]	S [c]	G [d]	Mercury	Noble Gas	Particulate	H-3 or C-14
Liquid or Sludge	Amalgamation Unit, Bleaching Unit, Centrifuge Unit, Filtration Module, Solidification System, Tank Farm, Area 612 and DWTF Transfers	0.0	1.0 (5.0E-2 for volatile inorganic acids)	0.0	1.0	1.0E-3 (1.0 for Filtration Module, Tank Farm, and Transfer Operations)	1.0	0.0	1.0E-3 (1.0 for Tank Farm and Transfer Operations)
Solid	Debris Washer, Pressure Reactor, Shredder/ Chopper, Size Reduction Unit, Solidification System, Water Reactor	3.0E-5	1.0 (5.0E-2 for volatile inorganic acids)	3.0E-5	1.0	1.0E-3	1.0	3.0E-5	1.0E-3

[a] L_1 designation represents nonradioactive compounds that are in liquid form at ambient temperatures but are not volatile.

[b] L_2 designation represents nonradioactive compounds that are in liquid form at ambient temperatures and are volatile.

[c] S designation represents nonradioactive compounds that are solid at ambient temperatures.

[d] G designation represents nonradioactive compounds that are gases at ambient temperatures.

Table III-4. Abatement Factors Assumed for the DWTF and Area 612 Treatment Units

Treatment Unit(s)	Abatement Device(s)	Abatement Factor According to Physical Form of Chemical					Abatement Factor According to Physical Form of Radionuclide		
		$L_1{}^a$	$L_2{}^b$	S^c	G^d	Mercury	Noble Gas	Particulate	H-3 or C-14
Liquid or Sludge Waste Streams									
Amalgamation Unit, Bleaching Unit, Centrifuge Unit, Tank Farm	Carbon canisters, 2 HEPA filters	1.0E-4	5.0E-2	1.0E-4	5.0E-2	1.0	1.0	1.0E-4	1.0
Filtration Module	Carbon canisters	1.0	5.0E-2	1.0E-2	5.0E-2	1.0E-2	1.0	1.0E-4	1.0
Solidification System	Carbon canisters, 1 HEPA filter	1.0E-4	5.0E-2	1.0E-4	5.0E-2	1.0	1.0	1.0E-4	1.0
Area 612 and DWTF Transfers	none	1.0	1.0	1.0	1.0	1.0	1.0	1.0E-4	1.0
Solid Waste Streams									
Debris Washer, Pressure Reactor, Water Reactor, Solidification System	Carbon canisters, 2 HEPA filters	1.0E-4	5.0E-2	1.0E-4	5.0E-2	1.0	1.0	1.0E-4	1.0 (H-3) 1.0E-4 (C-14)
Size Reduction Unit, Shredder/Chopper	2 HEPA filters	1.0E-4	1.0	1.0E-4	1.0	1.0	1.0	1.0E-4	1.0 (H-3) 1.0E-4 (C-14)

[a] L_1 designation represents nonradioactive compounds that are in liquid form at ambient temperatures but are not volatile.

[b] L_2 designation represents nonradioactive compounds that are in liquid form at ambient temperatures and are volatile.

[c] S designation represents nonradioactive compounds that are solid at ambient temperatures.

[d] G designation represents nonradioactive compounds that are gases at ambient temperatures.

Table III-5. Daily and Hourly Operating Capacities Assumed for Maximum Hourly Emission Calculations

Name of Treatment Unit	Maximum Daily Treatment Capacity from Part A Permit Application	Maximum Daily Treatment Capacity (kg/d)	Maximum Hourly Treatment Capacity (kg/h; based on 8 h/d of operation)
Amalgamation Unit[a]	0.09 short tons/d	8.48E+1	1.06E+1
Bleaching Unit[a]	0.28 short tons/d	2.55E+2	3.18E+1
Centrifuge Unit	12,000.00 gal/d	4.54E+4	5.68E+3
Debris Washer	0.50 short tons/d	4.55E+2	5.68E+1
Filtration Module	720.00 gal/d	2.73E+3	3.41E+2
Pressure Reactor[a]	0.09 short tons/d	8.48E+1	1.06E+1
Shredder/Chopper	0.50 short tons/d	4.55E+2	5.68E+1
Size Reduction Unit	5.00 short tons/d	4.55E+3	5.68E+2
Solidification System	6.00 short tons/d	5.45E+3	6.82E+2
Tank Farm	45,000.00 gal/d	1.70E+5	2.13E+4
Area 612 Transfers[b]	see reference[b]	see reference[b]	see reference[b]
DWTF Transfers[b]	see reference[b]	see reference[b]	see reference[b]
Water Reactor[a]	0.09 short tons/d	8.48E+1	1.06E+1

[a] The Part A Permit Application (LLNL, 1996) lists a single combined capacity of 0.28 short tons/d applicable collectively to the Uranium Bleaching Unit and the Small-scale Treatment Units: Pressure, Water and Amalgamation Reactors. However, in order to calculate specific operational capacities, it is assumed that the Bleaching Unit has a maximum daily capacity of 0.28 short tons/d, and that each of the individual reactors of Small-scale Treatment have one-third of that capacity (0.09 short tons/d).

[b] Annual and hourly treatment capacities for the waste transfer operations at the Area 612 Facility and the DWTF are determined based on the maximum throughput of individual chemicals based on 1992 and 1993 actual data (McDowell-Boyer *et al.*, 1995).

Section IV.

Description of the Dispersion Model for Chemical Compounds

PART IV. DESCRIPTION OF THE DISPERSION MODEL FOR CHEMICAL COMPOUNDS

IV.1   Introduction

IV.1.1   Dispersion Modeling

The movement of gases in the atmosphere is governed by the motions of the atmosphere. Some atmospheric motions dictate the paths to be followed by airborne contaminates; other motions determine the extent to which the contaminants will be diluted. Numerous field experiments over the last 75 years have yielded greater insight into the relationship between wind fluctuations and pollutant dispersal. These experiments have revealed a bell-shaped, or Gaussian, character of the average crosswind and vertical concentration distribution. Equations have been assembled to relate downwind concentrations to the vertical and horizontal concentration distribution function in a plume as a function of distance, meteorology, and character of surface. These techniques have received extensive technical review and wide acceptance.

A series of equations are needed to model dispersion under various source configurations and meteorological conditions. These equations can be written into a computer program, and many such programs have been approved by the U.S. Environmental Protection Agency (EPA) for use in a wide variety of situations. Computerized dispersion models have the capability of simulating different situations, such as building downwash, plume rise, and various source configurations. Other options involve the use of urban or rural dispersion parameters, different forms of receptor configurations, different selections of averaging times, and different configurations of outputs. A receptor is a hypothetical human subject or air sampler for which a calculation is made of air concentration, air dose, or deposition at that particular location.

IV.1.2   Model Selection

Regulatory applications of dispersion models should conform to the criteria set forth in the *Guideline on Air Quality Models* (EPA, 1986). Additional guidance is often available from local agencies, which in this case is the Bay Area Air Quality Management District (BAAQMD). The modeling application should be carried out in accordance with a modeling protocol that is reviewed and approved by the appropriate agency prior to conducting the modeling. The modeling protocol should identify the specific modeling options and input data to be used for a particular application. BAAQMD has approved modeling methods for this project.

The EPA-approved computer model, Industrial Source Complex-Short Term, Version 3 (ISC-ST3), has been selected to model the constituents released from Lawrence Livermore National Laboratory's (LLNL) Hazardous Waste Management (HWM) facilities. The ISC-ST3 model is a steady-state, Gaussian, plume model that can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial source complex (EPA, 1995). ISC-ST3 includes several options for modeling air quality impacts of pollutant sources, making it a popular choice among the air dispersion modeling community. The ISC-ST3 computer model allows for the selection of a series of regulatory options which will force the

model to execute according to the preferences of the EPA. Options that deviate from the regulatory standard must be defined by using descriptive keywords. The input parameters are completely documented in the input and output files (see **Supplement B**).

The ISC-ST3 model is capable of handling multiple sources, including point, volume, and area source types. The model has considerable flexibility to utilize formatted computer files that contain sequential hourly records of meteorological variables. Multiple receptor networks may be included in a single computer run. The receptor networks may be a mix of discrete points, Cartesian, and polar grids. This flexibility is useful for the current project in order to establish a grid over the whole modeling domain and to include a list of receptors representing specific buildings at discrete locations.

The two basic types of output available with ISC-ST3 are overall maximum concentration and annual-average concentration for each receptor. We have used multiple years of meteorological data, and the maximum-hour and annual-average concentrations were computed for each of the years. As suggested by the EPA, the maximum-hour concentrations used for the risk calculations will be the highest of maximum-hour concentrations from all modeled years, and the annual-average concentration used will be the average of the annual-average concentrations from all modeled years.

IV.1.3   Source Characterization

We have modeled the atmospheric dispersion of volatile compounds that may be emitted from operations at the HWM facilities at the proposed Decontamination and Waste Treatment Facility (DWTF) and the Area 612 Facility. The modeling of radiological waste is discussed in **Section VIII**. The atmospheric dispersion and dose conversion model, CAP88-PC, was used exclusively for the modeling of radiological waste.

The substances are modeled as nonbuoyant, chemical compounds. We assumed the emission rates are constant under all conditions. The dispersion characteristics of all the compounds are similar enough to be considered equivalent. The settling velocity is set to "0" in order to yield conservative results. Large particles that could settle are effectively filtered by the HEPA filters. The settling velocity is a positive value when the substance to be modeled is a particle that will drift downward, leading to lower concentrations at locations further downwind. The reflection coefficient is set to "1.0" so that the plume will not be depleted from impacting with the ground. This ensures that 100% of the plume remains in the air to contribute to downwind concentrations.

We have identified four locations for air emission from HWM operations: the DWTF stack, the Area 612 Facility stack, and blending/transfer operations at the DWTF yard and in the Area 612 Facility yard.

IV.1.3.1   DWTF Facility Stack Source

The majority of the emissions from HWM operation will be collected in the Air Emission Control System. Depending on the operation, the effluent will be filtered once or twice by HEPA filters. All the emissions from the DWTF building are vented through the 20-m-tall stack with an

inside diameter of 1.98 m and exit velocity of 10.9 m/s. These values were selected because they resulted in lower plume heights.

IV.1.3.2   DWTF Facility Surface Source

Another source at DWTF is associated with the blending/transfer operation which involves the transfer of liquid waste from small containers into larger containers. This operation occurs near the surface just north of the DWTF building and does not involve ventilation that would add to vertical displacement of the plume.

IV.1.3.3   Area 612 Facility Stack Source

The Size Reduction Unit at the Area 612 Facility is filtered through a double HEPA system and vented through a 10-m-tall stack with an inside diameter of 0.61 m and exit velocity of 16.2 m/s.

IV.1.3.4   Area 612 Facility Surface Source

Another source at the Area 612 Facility is associated with the blending/transferring of liquid waste from storage tanks to tanker trucks for off-site shipment. This operation takes place near the east edge of the area, just east of Trailer-6179 (T6179). This source was modeled as a single point located near the surface to yield conservative estimates of downwind concentrations.

IV.1.3.5   Building Downwash

The two stack sources are associated with buildings that have very little influence on the plume rise. Nevertheless, these buildings were analyzed with the EPA's Building Profile Input Program (BPIP) (EPA, 1993). BPIP correctly calculates the building heights and projected building widths, and these values were entered in the ISC-ST3 model (**Supplement B**).

IV.1.4   Unit Emission Rates

A single model run can be used to calculate dispersion of all the compounds by employing a release rate (Q) of 1 g/s (also known as the unit emission rate). For each year of the simulation, the model will calculate the average and the maximum concentrations that are normalized to the unit release rate. Deposition amounts will not be modeled directly, but they can be calculated by multiplying the surface air concentration by a deposition rate. The normalized concentration, either annual average or maximum hour, is typically identified as χ/Q (Chi over Q). To calculate downwind concentrations (χ) resulting from a given release rate at either location, we multiplied the normalized concentration (with units of seconds per cubic meter) by the actual release rate in grams per second. The resulting concentration has units of grams per cubic meter, and each source contributes to the total concentration at a given receptor location. Assuming the background concentration of the compound is negligible, we obtain the total concentration at a particular receptor by adding the concentrations from all sources.

IV.1.5   Receptor Selection

Concentrations were computed for four categories of receptors: off-site worker, on-site worker, nearby resident, and child care center. The receptor locations were carefully surveyed in conjunction with a preliminary run of ISC-ST3 model to reveal areas receiving the highest average-annual or maximum-hour concentrations resulting from HWM operations.

Nearby off-site workers of particular interest are located in the industrial park north of Patterson Pass Road between Vasco and Greenville Roads. A field survey also located several business and residences that represent off-site workers and nearby residents.

Receptors representing a hypothetical child care center were located in two residential areas featuring the highest concentrations from HWM operations. One residential area is located near the intersection of Vasco Road and East Avenue. A receptor was placed at the leading edge of this residential area and is designated CDC-1. The other residential area is located near the main entrance to LLNL northwest of the intersection of Vasco Road and Westgate Drive. Receptors were placed at the upwind and downwind edges of this residential area, designated CDC-2 and CDC-3, respectively. These two receptors establish the range of concentrations in that residential area.

IV.2   Application of the ISC-ST3 model

Figure IV-1 is a diagram of the data flow when running the ISC-ST3 model. The input data required for a single computer simulation are one year of hourly averaged meteorological data, and geographic locations of the sources and receptors. Other input parameters include commands to compute maximum hour and annual averages at all receptors, and emission rates of each source. For every hour in the year-long meteorological record, the model will compute the dispersion to all receptors. The ISC-ST3 model keeps track of the maximum hourly and overall annual-average concentration at each receptor.

Most of the regulatory defaults in the computer model have been utilized. What follows is a detailed description of the inputs to the ISC-ST3 model and the resulting model output.

IV.2.1   Model Inputs

The ISC-ST3 model allows input with descriptive keywords that are accompanied by the user-supplied value for the respective parameter. Model input is organized into four groups: Control, Source, Receptors, and Meteorology.

IV.2.1.1   Control

Dispersion parameters (σ_x and σ_y) have been calculated in the rural mode as described in the *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models* (EPA, 1995). We used the regulatory default values for the wind profile exponents and vertical potential temperature gradient.

IV.2.1.2　　Source

The stack sources are specified in the ISC-ST3 model as previously stated. The two blending/transfer sources at the DWTF Facility and the Area 612 Facility sources are closely approximated in the model as small areas near the surface. These sources have been modeled as square, with sides that are 5 m in length. **Figure IV-2** is a scale map of LLNL and vicinity featuring the locations of HWM facilities. The Universal Transverse Mercator (UTM) coordinates of the DWTF Facility stack are 4172403 North 614791 East (UTM Zone 10), and the surface source is 30 m north of the stack. The UTM coordinates of the Area 612 Facility stack are 4171105 North 614763 East (UTM Zone 10). The Area 612 Facility surface source is 4171192 North 614739 East (UTM Zone 10).

IV.2.1.3　　Receptors

We used multiple receptor networks when running the ISC-ST3 model. The receptors are divided into two groups: grid and discrete. For all receptor groups, receptors within 10 m of the center of either source were rejected. Annual-average and maximum one-hour-average surface concentration were computed at all receptors.

IV.2.1.3.1　　Gridded Receptors

A large Cartesian grid of 5 km on a side and near the DWTF was used to predict concentrations in the general vicinity of LLNL. The large grid has 441 receptors (21×21) spaced in 250-m intervals. The southwest corner of the large Cartesian grid has UTM coordinates of 417000 North 612250 East.

The 441 grid receptors were divided into two groups: receptors inside the LLNL boundaries and those outside the boundaries. The 52 receptors located inside the LLNL boundaries can be used to estimate concentrations experienced by on-site workers.

IV.2.1.3.2　　Discrete Receptors

Table IV-1 lists additional receptors at locations of maximum exposure to nearby residents and off-site workers from HWM operations. The locations of these discrete receptors are noted on **Figure IV-2**. Several residences were identified as described in **Section IV.1.5**. There are 56 discrete receptor locations.

IV.2.1.4　　Meteorology

On-site data was employed for meteorological input to the ISC-ST3 model. The data has been collected near the northwest corner of the Livermore site since 1985. This meteorological system is maintained by the Terrestrial & Atmospheric Monitoring & Modeling Group of LLNL. Every six months the system is calibrated and audited by the U.S. Bureau of Land Management. This tower features anemometer and temperature sensors at the 10- and 40-m levels.

The LLNL meteorological tower is 0.9 miles (1.5 km) west of the DWTF stack, 1.3 miles (2.0 km) northwest of the Area 612 Facility, and 2.3 miles (3.7 km) west of the furthest discrete

receptor. The meteorological data from this tower site were deemed appropriate by BAAQMD for use in modeling dispersion from locations in and around LLNL.

The meteorological system has been maintained and the data were processed according to guidelines in *Quality Assurance Handbook for Air Pollution Measurement Systems. Volume IV. Meteorological Measurements* (EPA, 1983) and *On-Site Meteorological Program Guidance for Regulatory Modeling Applications* (EPA, 1987).

Meteorological data for five years (1990 through 1994) have been compiled into hourly averages. EPA guidance indicates that five years of representative meteorological data should be used when estimating concentrations with an air quality model. This ensures that worst-case meteorological conditions are adequately represented in the model results. The meteorological data set used for the current modeling yields 43,571 hourly averages at the 10-m level which represents 99.4% recovery over the 5-year period. EPA guidelines require that data recovery be greater than 90%.

Figure IV-3 is a wind rose from the five years of meteorological data. **Table IV-2** is the tabular form of the same joint-frequency data which simply show the percentage of occurrence of the winds in the given wind speed range and from a particular direction. The width of the barb segment in the figure indicates the wind speed class. The length of each barb segment is proportional to the frequency of wind from the indicated direction and in the respective wind speed class.

The LLNL meteorological data were processed into files ready for the ISC-ST3 model. The processing includes adjustment of the wind during times of calm winds, computation of stability class, adjustment of stability class, and inclusion of mixing height.

Calm winds are identified as winds with magnitudes less than the threshold of the anemometer set. The threshold of the LLNL anemometer is 0.5 m/s (1 mph). Winds below this magnitude are not forceful enough to push the wind vane towards the correct direction. The EPA and the BAAQMD recommend that during calm periods the wind speed is set to the threshold (0.5 m/s) and the wind direction is equal to the previous hour's wind direction.

Stability is computed using the Modified Sigma Theta method recommended in *On-Site Meteorological Program Guidance for Regulatory Modeling Applications* (EPA, 1987). The stability class is further adjusted so that it cannot change by more than one class per hour.

The mixing height is not currently monitored at LLNL. BAAQMD recommends a constant value of 600 m for mixing height. Although a constant value is unrealistic, mixing height values will not substantially affect the calculation of concentrations within 3 km from the source.

IV.2.2 Model Output

Normalized concentrations (χ/Q) from each source are presented in the data tables and figures referred to in this section as described earlier in **Section IV.1.2**. The annual averages presented are the arithmetic average of the annual average from each of all five model runs. The maximum-hour data presented here are the highest value of the five maximum hourly values from the model

runs described in **Section IV.1.4**. To obtain the concentration of a single compound at a given receptor location resulting from emissions of a particular source, we multiply the emission rate of that compound in units of grams per second by the normalized concentration modeled for the source/receptor combination. The result has units of grams per cubic meter. For total average-annual concentration from all HWM operations of a single compound at a receptor location, we simply add the contributions from all four sources. The normalized maximum-hour concentrations should not be combined from different sources. The meteorological conditions that produce a maximum-hour concentration at a given receptor will yield negligible concentrations from the other sources.

IV.2.2.1   Selected Receptors

Table IV-3 shows the normalized, annual-average concentrations at the three discrete receptors that were found to produce the maximum risk in their class. Risk is explained and calculated in **Sections VI** and **VII**. The receptor names in **Table IV-3** are also described in **Section VI**. The hypothetical resident was selected from the 389 off-site gridded receptors as the location of highest, off-site residential risk and is located at UTM coordinates of 4172500 N 615250 E. The position of the hypothetical resident receiving the maximum risk is noted in **Figure IV-2**. The adult worker on site was selected from the 52 on-site, gridded receptors with the highest worker risk and is located at 4171250 N 614750 E. The position of the adult worker receiving the maximum risk is noted in **Figure IV-2**.

Table IV-4 lists the highest values for normalized maximum-hour concentrations for the four sources. As described previously in **Section IV.2.2**, the maximum-hour concentration from different sources cannot be combined. This is because the meteorological conditions that create a maximum-hour concentration for a particular source-receptor paring will not yield a significant concentration to that same receptor from another source.

IV.2.2.2   Graphical Model Output

The results from the 441 gridded ISC-ST3 receptors are presented in eight figures labeled **Figure IV-4** through **Figure IV-11**. The first four display normalized annual average concentrations (**Figure IV-4** through **Figure IV-7**), the last four (**Figure IV-8** through **Figure IV-11**) display normalized, maximum-hour concentrations.

It is evident by the model results that there are several differences between the annual-average and maximum-hour normalized concentrations. The stack and surface releases also display characteristic differences.

The annual average is strongly influenced by the frequency of wind blowing from the source to the receptor. The field of annual averages of χ/Q shown in **Figure IV-4** through **Figure IV-7** reflects the wind rose in **Figure IV-3**. The bulge of higher annual-average concentrations is toward the northwest. The surface sources (**Figure IV-5** and **Figure IV-7**) feature the highest concentrations closest to the release point. In contrast, the elevated release from stack sources (**Figure IV-4** and **Figure IV-6**) allow the effluent to translate downstream and become dilute in the ambient flow.

For the two stack sources, the maximum-hour concentrations occur during the daytime (**Figure IV-8** and **Figure IV-10**). At these times the unstable conditions draw the effluent more quickly to the receptors at the surface. These meteorological conditions occur when the wind is from the west as evidenced by the higher maximum-hour concentrations east of the stack sources.

Conversely, the maximum-hour concentrations for the two surface releases (**Figure IV-9** and **Figure IV-11**) occur during the night when the wind speed is very low. These meteorological conditions occur at least once for every wind direction. The resulting pattern of equal values of normalized maximum-hour concentrations appears as concentric circles around the source.

IV.3 References

U.S. Environmental Protection Agency (EPA). 1983. *Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV. Meteorological Measurements.* U.S. Department of the Interior, Environmental Protection Agency, Research Triangle Park, NC, February, EPA-600/4-82-060.

U.S. Environmental Protection Agency (EPA). 1986. *Guideline on Air Quality Models.* Revised. U.S. Department of the Interior, Environmental Protection Agency, Research Triangle Park, NC, July, EPA-450/2-78-027R.

U.S. U.S. Environmental Protection Agency (EPA). 1987. *On-Site Meteorological Program Guidance for Regulatory Modeling Applications*. U.S. Department of the Interior, Environmental Protection Agency, Research Triangle Park, NC, July, EPA-450/4-87-013.

U.S. Environmental Protection Agency (EPA). 1992. *User's Guide for the Industrial Source Complex (ISC2) Dispersion Models*. U.S. Department of the Interior, Environmental Protection Agency, Research Triangle Park, NC, March, EPA-450/4-92-008.

U.S. Environmental Protection Agency (EPA). 1993. *User's Guide to the Building Profile Input Program.* U.S. Department of the Interior, Environmental Protection Agency, Research Triangle Park, NC, October, EPA-454/R-93-038.

U.S. Environmental Protection Agency (EPA). 1995. *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models*. U.S. Department of the Interior, Environmental Protection Agency, Research Triangle Park, NC, September, EPA-454/B-95-003a.

Appendix includes listing of an ISC-ST3 input file.

IV.4 Acronyms

BAAQMD   Bay Area Air Quality Management District

BPIP   Building Profile Input Program

EPA   U.S. Environmental Protection Agency

ISC-ST3   Industrial Source Complex—Short Term, Version 3

UTM   Universal Transverse Mercator

Input	Atmospheric dispersion model	Output

LLNL meteorological data (formatted for model by BAAQMD)

Geographic locations (UTM coordinates) for facilities (DWTF and Areas 612)

ISC-ST3

$$\frac{\chi \left(\text{concentration; } \frac{g}{m^3} \right)}{Q \left(\text{unit emission rate; } \frac{g}{s} \right)}$$

Receptor locations
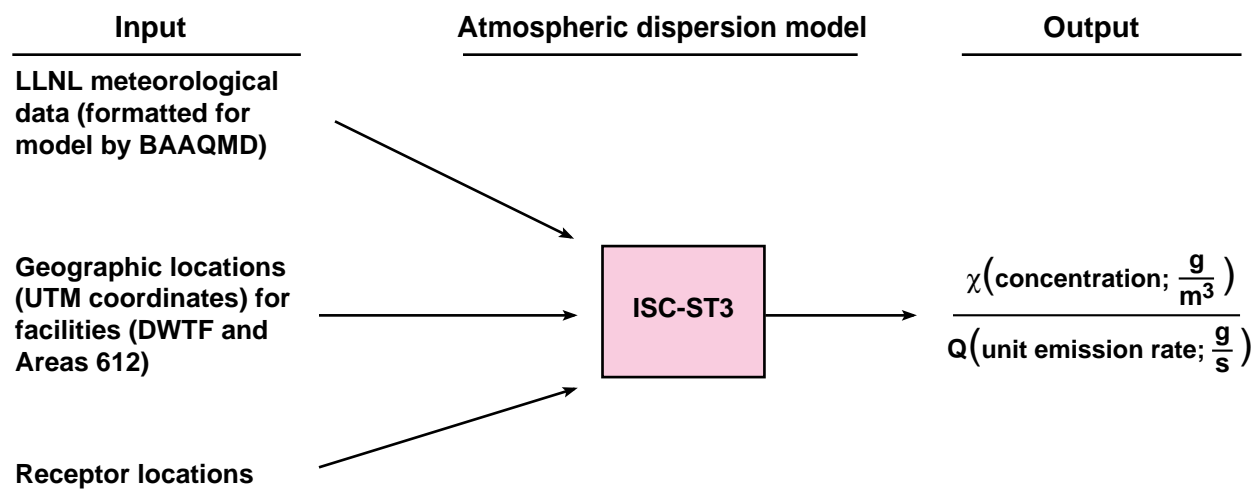
Figure IV-1.   Data flow diagram for the ISC-ST3 model
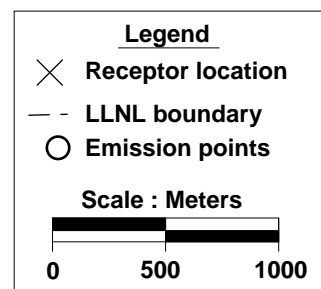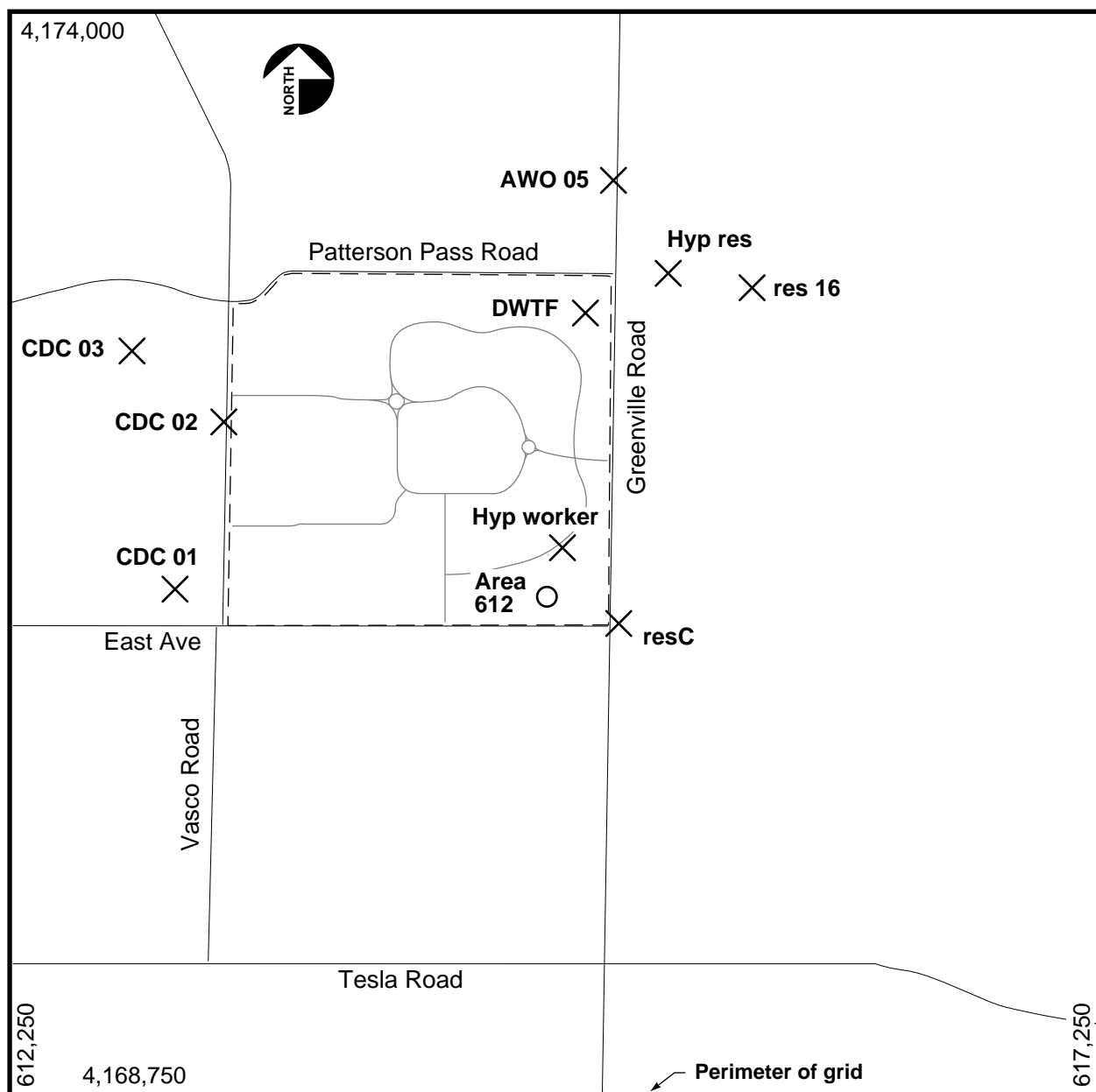
Figure IV-2. **Scale map of LLNL and vicinity showing the emission points, discrete receptors, and receptor grid**

(Note: The numbers at the perimeter are the UTM coordinates on meters.)
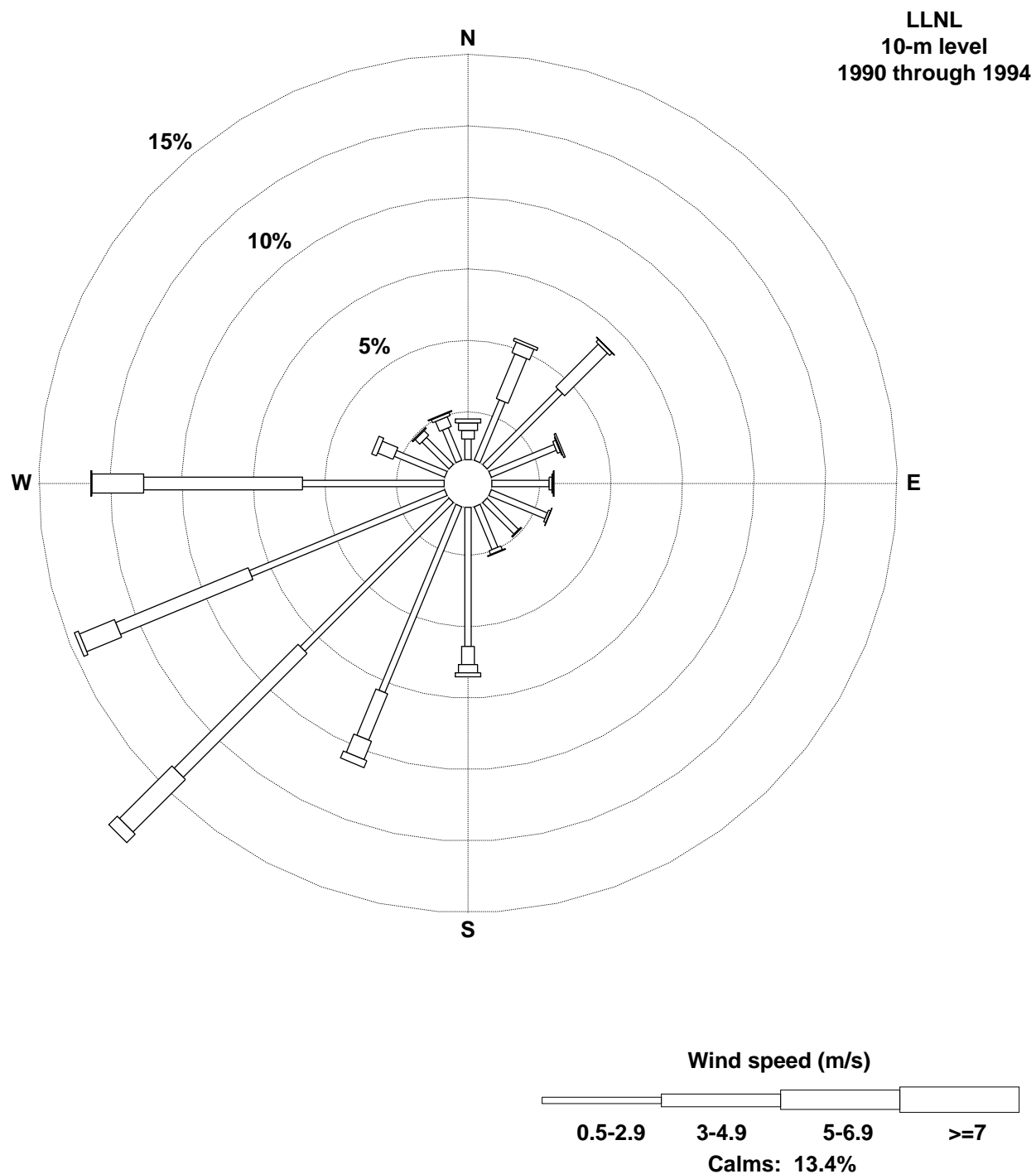
Figure IV-3.   Wind rose of meteorological data used in the dispersion model
              (Note: This diagram combines 5 years of data measured at the LLNL tower.)
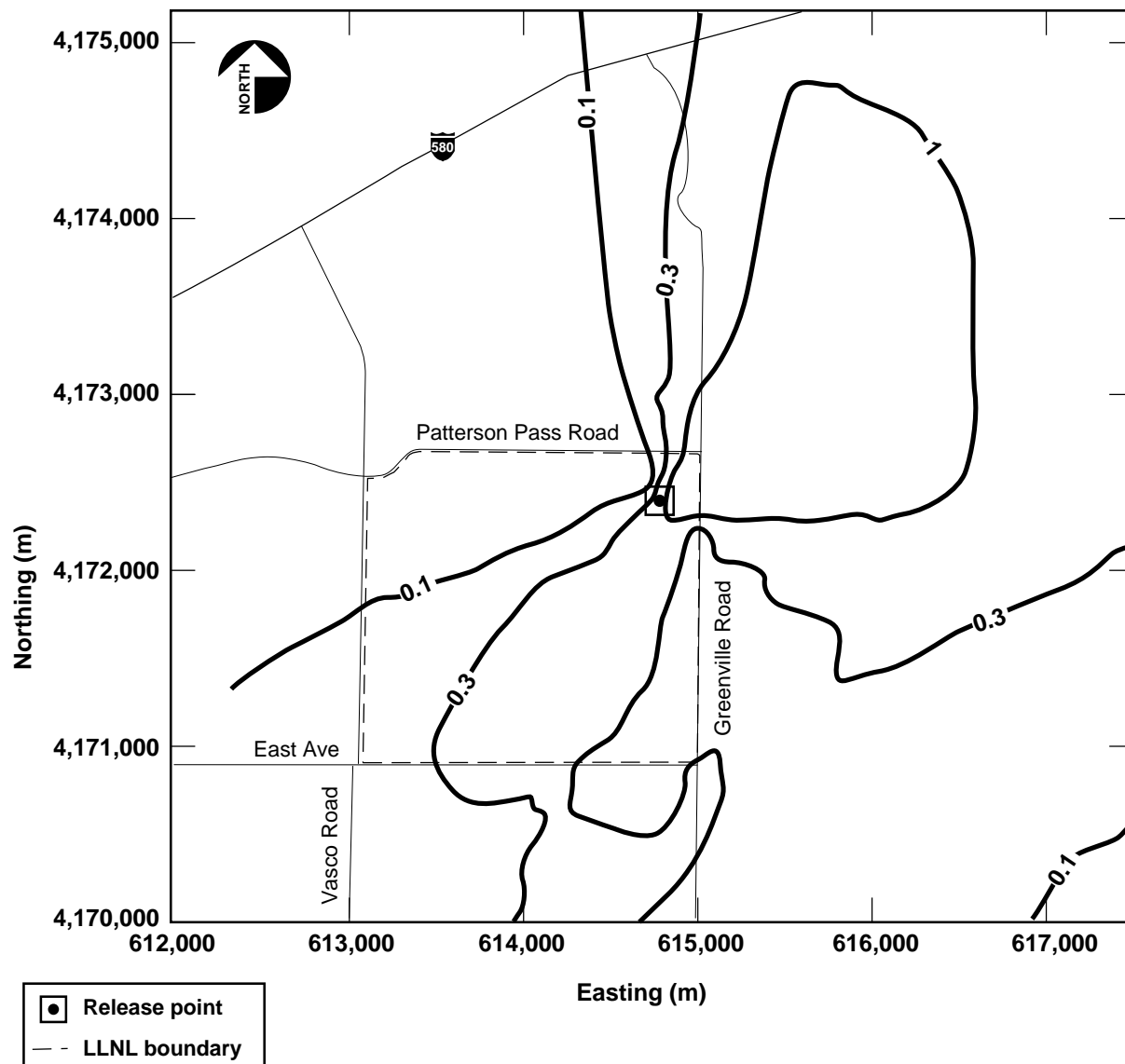
Figure IV-4.   Contours of equal values of annual-average χ/Q resulting from modeled emission from the DWTF stack

(Units of χ/Q are 10^{-6} seconds per cubic meter.)
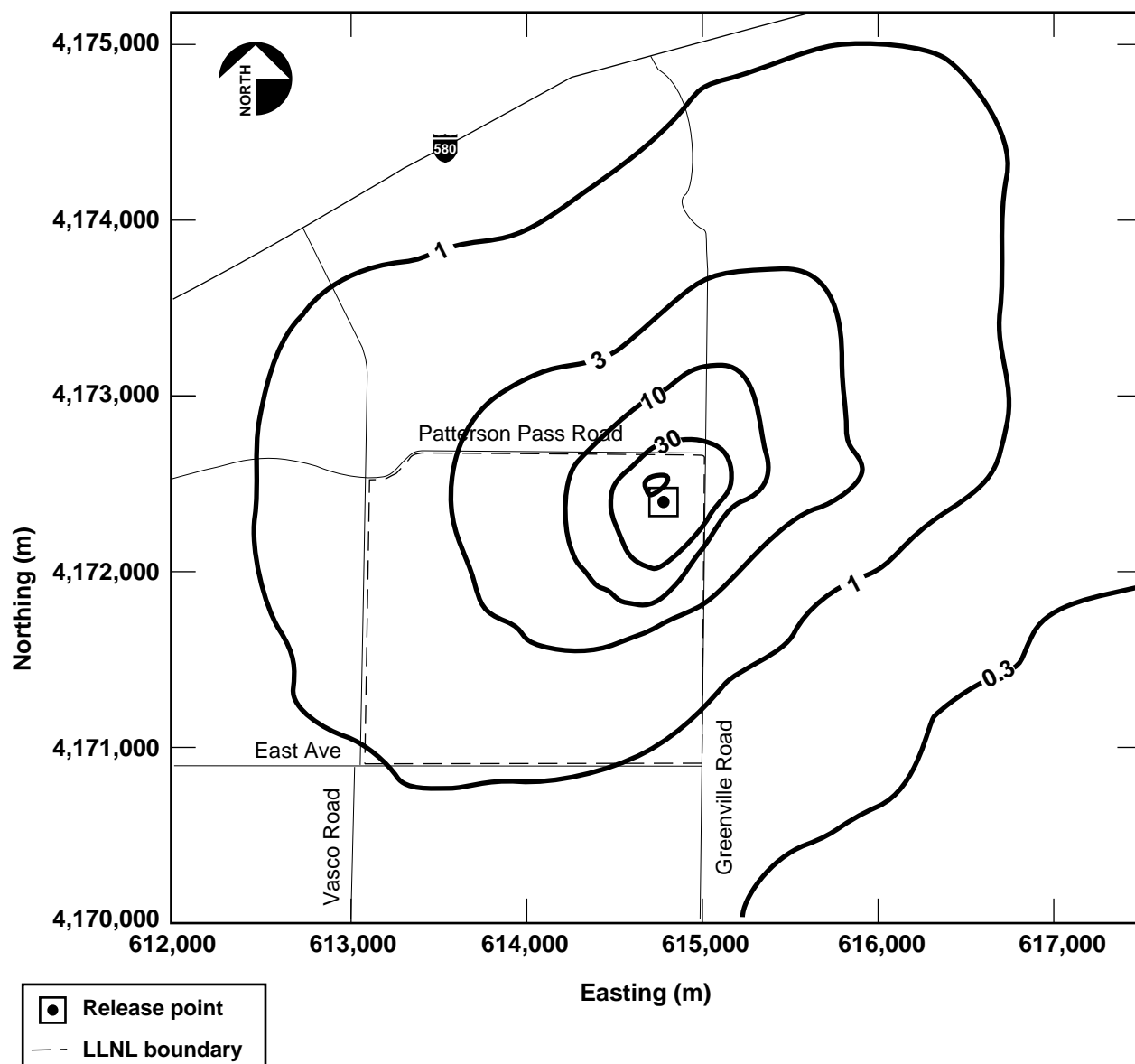
Figure IV-5. **Contours of equal values of annual-average χ/Q resulting from modeled emission from the DTWF blending operation**
(Units of χ/Q are 10⁻⁶ seconds per cubic meter.)
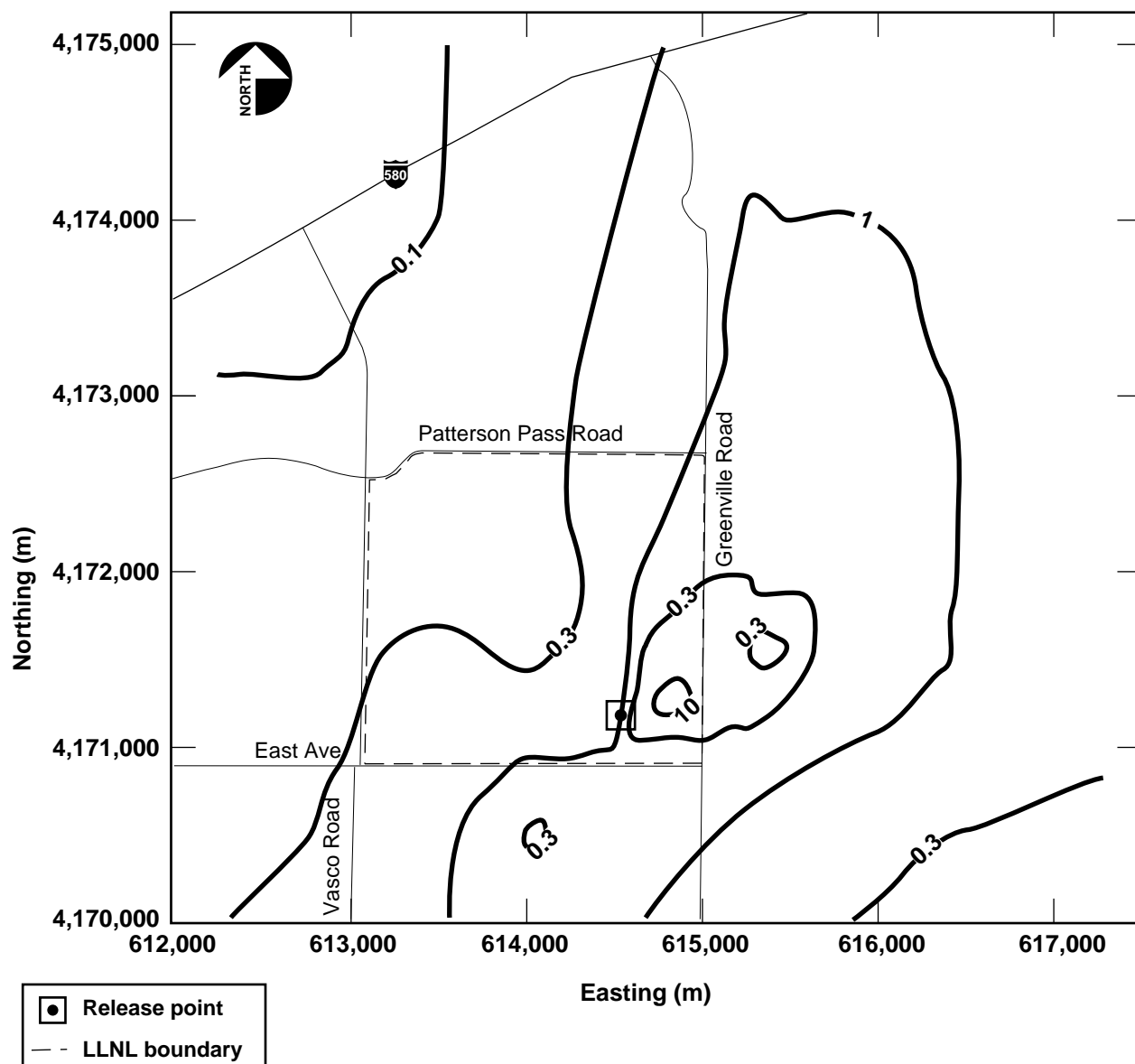
Figure IV-6. **Contours of equal values of annual-average χ/Q resulting from modeled emission from the Area 612 stack**

(Units of χ/Q are 10^{-6} seconds per cubic meter.)
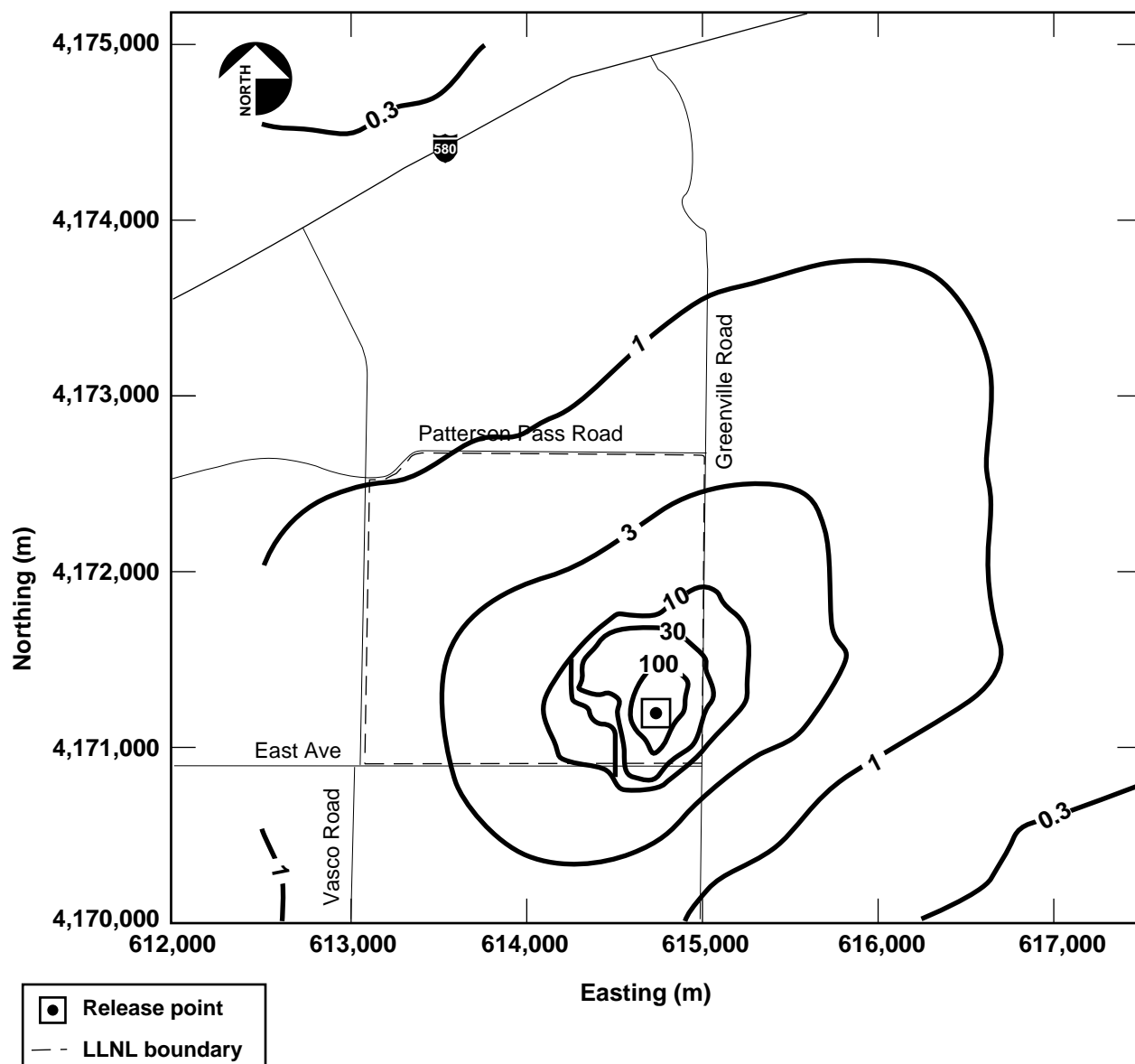
Figure IV-7. Contours of equal values of annual-average χ/Q resulting from modeled emission from the Area 612 blending operation
(Units of χ/Q are 10⁻⁶ seconds per cubic meter.)
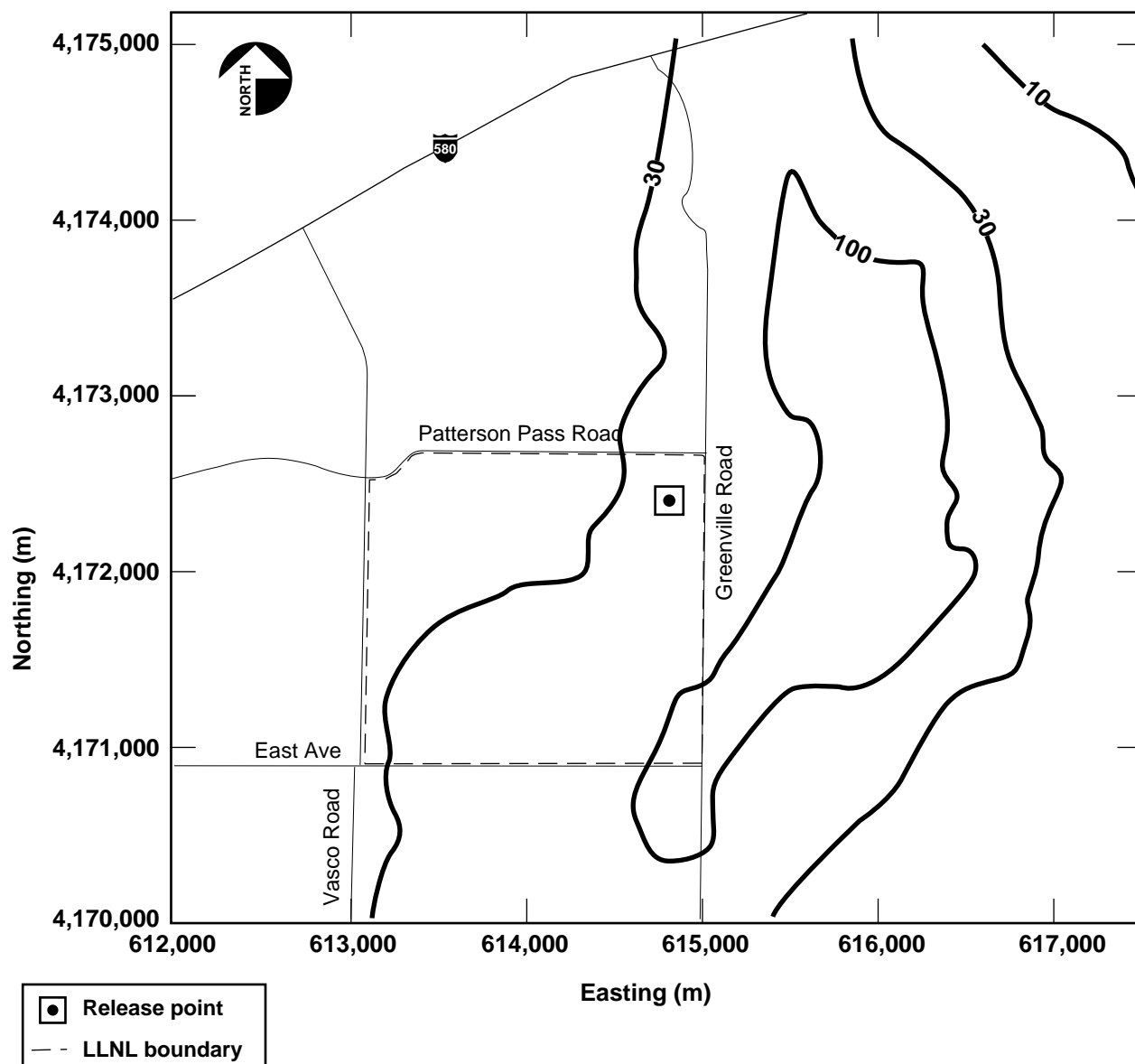
Figure IV-8.   Contours of equal values of maximum-hour χ/Q resulting from modeled emission from the DWTF stack

(Units of χ/Q are 10^{-6} seconds per cubic meter.)

4,175,000

100

NORTH

580

4,174,000

300

4,173,000

1,000

Patterson Pass Road

3,000

Northing (m)

4,172,000

4,171,000

East Ave

Vasco Road

Greenville Road

4,170,000

612,000   613,000   614,000   615,000   616,000   617,000

Easting (m)

▣ **Release point**

– – **LLNL boundary**
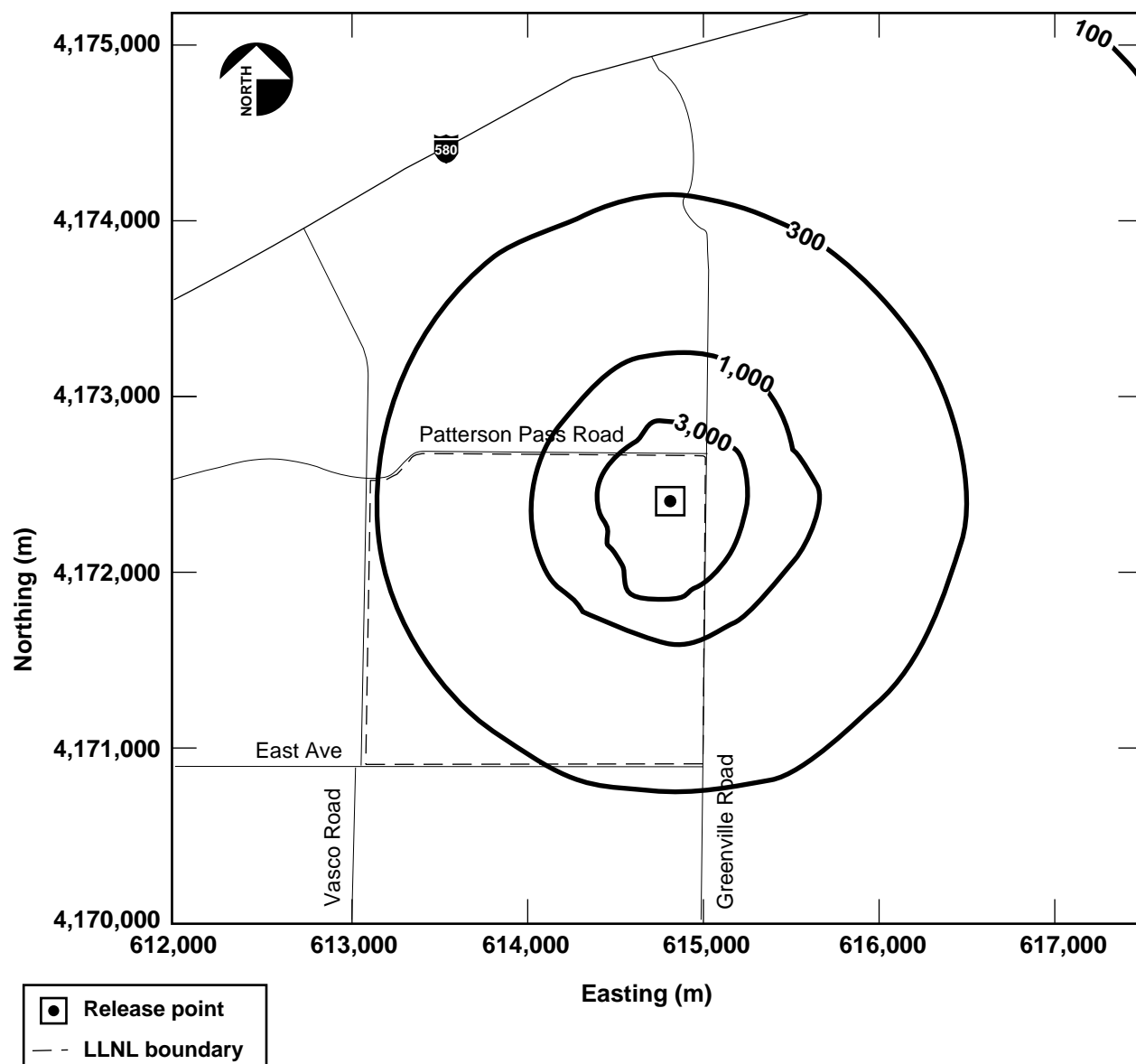
Figure IV-9.   Contours of equal values of maximum-hour χ/Q resulting from modeled emission from the DTWF blending operation
(Units of χ/Q are 10^{-6} seconds per cubic meter.)
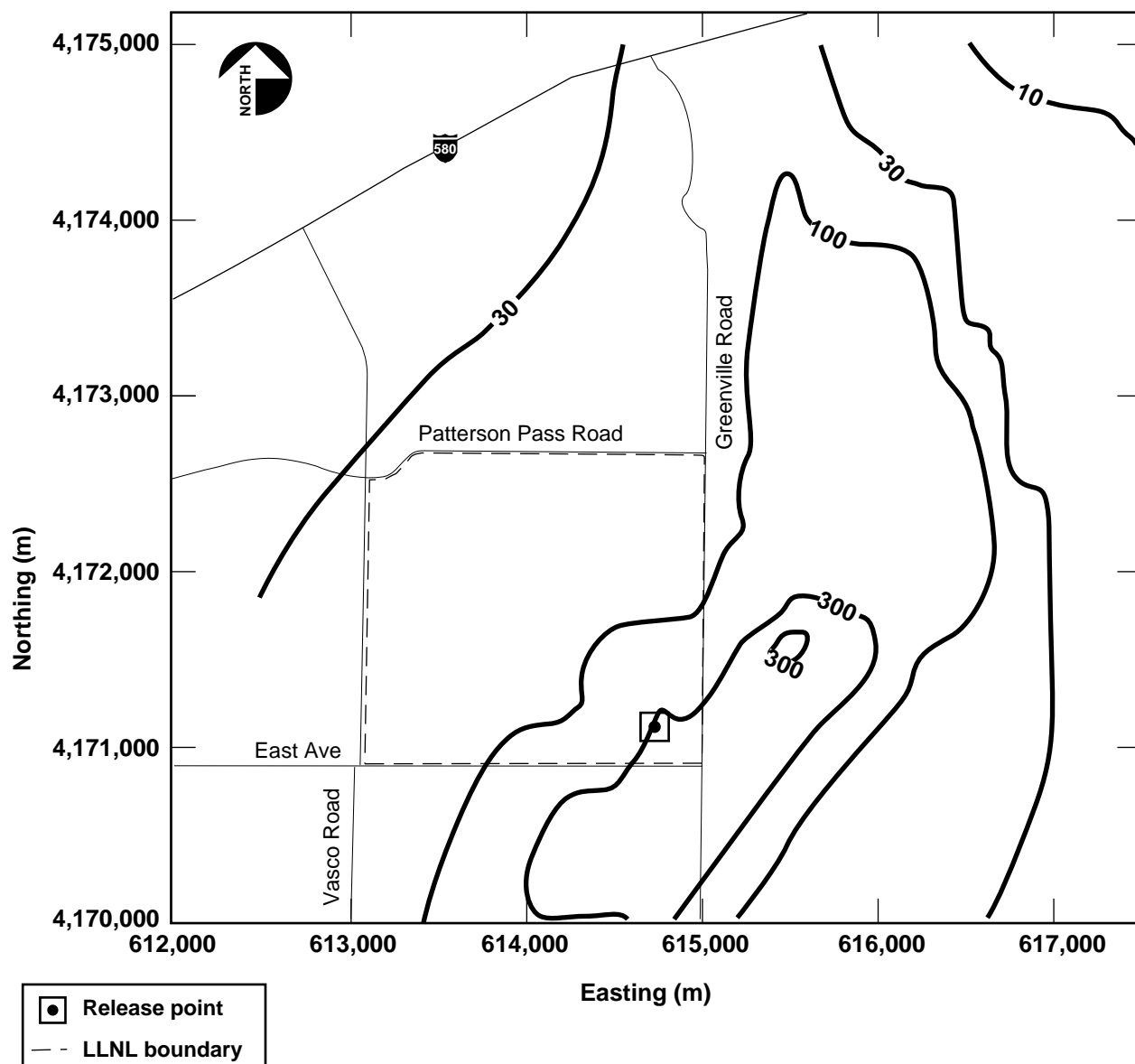
Figure IV-10. **Contours of equal values of maximum-hour χ/Q resulting from modeled emission from the Area 612 stack;**
(Units of χ/Q are 10^{-6} seconds per cubic meter.)
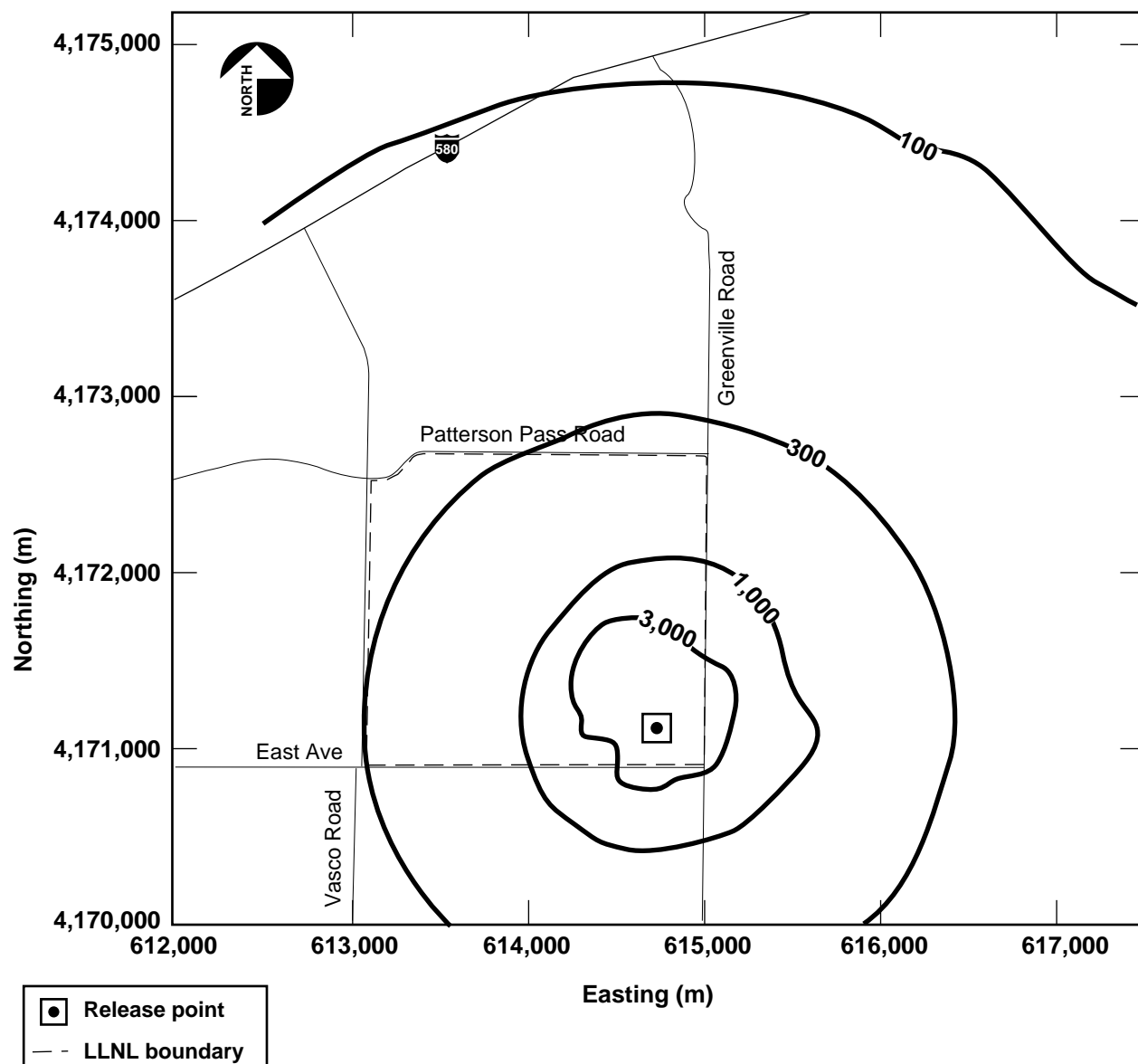
Figure IV-11. Contours of equal values of maximum-hour χ/Q resulting from modeled emission from the Area 612 blending operation
(Units of χ/Q are 10^{-6} seconds per cubic meter.)

Table IV-1.   Locations of discrete receptors modeled by ISC-ST3

Location	Northing[a]	Easting[a]	Elev.[b]	Location	Northing	Easting	Elev.
Child daycare				AWO-04	4172669	614576	181
CDC-01	4171051	613007	181	AWO-05	4172931	614944	186
CDC-02	4171948	613071	177	AWO-06	4173076	614935	186
CDC-03	4172357	612838	171	AWO-07	4173068	614627	183
Residences				AWO-08	4172931	614844	185
RES-01	4171457	615072	211	AWO-09	4173076	614844	185
RES-02	4170862	615055	223	AWO-10	4172931	614744	183
RES-03	4170922	615066	221	AWO-11	4173076	614744	183
RES-04	4173360	614424	177	AWO-12	4172691	614534	181
RES-05	4173316	614486	178	AWO-13	4173006	614571	180
RES-06	4173197	614565	177	AWO-14	4172805	613421	172
RES-07	4172890	615762	202	AWO-15	4172673	613423	173
RES-08	4172651	616988	232	AWO-16	4172691	614434	180
RES-09	4172427	616592	219	AWO-17	4173006	614434	180
RES-10	4171795	616889	241	AWO-18	4172691	614334	179
RES-11	4171827	616919	235	AWO-19	4173006	614334	178
RES-12	4171850	616644	221	AWO-20	4172691	614234	178
RES-13	4171746	616204	213	AWO-21	4173006	614234	178
RES-14	4171765	615762	198	AWO-22	4172691	614134	178
RES-15	4171748	615686	198	AWO-23	4173006	614134	177
RES-16	4172429	615531	198	AWO-24	4172849	614434	180
RES-17	4172064	615171	190	AWO-25	4172849	614334	177
RES-18	4172069	615196	190	AWO-26	4172849	614234	178
RES-19	4173166	614822	183	AWO-27	4172849	614134	177
Industrial				AWO-28	4172666	613785	175
Veterinarian	4172154	615035	189	AWO-29	4172670	613390	173
Credit Union	4171475	614950	189	AWO-30	4172800	613382	172
AWO-01	4172712	616986	209	AWO-31	4172749	613134	171
AWO-02	4172920	614611	182	AWO-32	4172519	613114	172
AWO-03	4172920	614978	187				

a   Northing and Easting are the UTM coordinates with units of meters.

b   Elevation is in meters above mean sea level.

Table IV-2. Frequency of wind (in percent) from the given direction and in the given wind speed class for LLNL from 1990 through 1994

	Wind Speed (m/s)					
Direction	0.0-0.4	0.5-2.9	3.0-4.9	5.0-6.9	=>7.0	Total (%)
NNE	0.84	2.29	1.69	0.40	0.10	5.3
NE	0.84	3.72	2.11	0.12	0.00	6.8
ENE	0.84	2.46	0.11	0.03	0.06	3.5
E	0.84	2.00	0.10	0.04	0.03	3.0
ESE	0.84	2.12	0.08	0.00	0.00	3.1
SE	0.84	1.55	0.04	0.00	0.00	2.4
SSE	0.84	1.62	0.14	0.03	0.00	2.6
S	0.84	4.86	0.63	0.29	0.14	6.8
SSW	0.84	7.03	1.75	0.69	0.26	10.6
SW	0.84	7.34	6.12	2.59	0.42	17.3
WSW	0.84	7.39	5.01	1.32	0.15	14.7
W	0.84	4.95	5.55	1.81	0.03	13.2
WNW	0.84	1.91	0.58	0.18	0.00	3.5
NW	0.84	1.33	0.23	0.04	0.00	2.4
NNW	0.84	1.23	0.37	0.11	0.03	2.6
N	0.84	0.72	0.30	0.26	0.14	2.3
Total	13.4%	52.5%	24.8%	7.9%	1.4%	100.0%

Table IV-3. Normalized annual-average concentrations (χ/Q) producing maximum risk from releases from all four sources

Location	Receptor name	DWTF Stack χ/Q (s/m^3)	DWTF Surface χ/Q (s/m^3)	Bldg 612 Stack χ/Q (s/m^3)	Area 612 Surface χ/Q (s/m^3)
CDC-01	MEI$_{cdc}$	1.7×10^{-7}	9.7×10^{-7}	2.8×10^{-7}	1.6×10^{-7}
RES-16	MEI$_{res-real}$	1.7×10^{-6}	4.9×10^{-6}	2.0×10^{-6}	3.1×10^{-6}
AWO-05	MEI$_{awo-os}$	3.4×10^{-7}	1.4×10^{-5}	6.3×10^{-7}	1.7×10^{-6}
Hypothetical resident	MEI$_{res-hyp}$	2.7×10^{-6}	1.5×10^{-5}	1.5×10^{-6}	3.0×10^{-6}
Adult worker on site	MEI$_{aos}$	2.8×10^{-7}	1.3×10^{-6}	5.9×10^{-7}	6.8×10^{-4}

Table IV-4. Highest normalized maximum-hour concentrations (χ/Q) resulting from releases from all four sources

(The position of the highest χ/Q is also provided.)

Source	Maximum 1-hour χ/Q	Northing[a]	Easting[a]
DWTF Stack	1.7×10^{-4}	615500	4173250
DWTF Area	9.7×10^{-3}	615000	4172500
Bldg 612 Stack	6.5×10^{-4}	615072	4171457
Bldg 612 Area	3.8×10^{-3}	614950	4171475

[a] Northing and Easting are the UTM coordinates with units of meters.

Section V.

Screening to Identify Exposure Pathways of Concern for Maximally Exposed Individuals (MEIs)

SECTION V. SCREENING TO IDENTIFY EXPOSURE PATHWAYS OF CONCERN FOR MAXIMALLY EXPOSED INDIVIDUALS (MEIs)

V.1. Introduction

The purpose of this section is to identify the Maximally Exposed Individual (MEI) receptors and to present the methodology used to screen and identify the exposure pathways of concern for these MEIs. The exposure scenarios that we evaluated as part of this process were identified with respect to two principal assumptions about present and future uses of land in the immediate vicinity of Lawrence Livermore National Laboratory (LLNL). These assumptions are that:

- LLNL will continue to be operated as a U.S. Department of Energy (DOE) facility.

- Waste handling and treatment in the Decontamination and Waste Treatment Facility (DWTF) and the Area 612 Facility will take place over a 30-year period (the approximate predicted operational lifetime of the planned facilities).

V.2 Scenarios Used

We developed five scenarios to evaluate potential human exposure to chemicals released from the DWTF and the Area 612 Facility. The first of these scenarios pertains to adults working off site (awo) in a commercial facility adjacent to LLNL. A second, similar scenario addresses exposures of adults working at LLNL (adult workers on site [aos]). Individuals are assumed to work in either of these locales over their entire period of employment (25 years). The third and the fourth exposure scenarios consider residential exposures, either at an existing (real) residence (RES_{real}) or at a hypothetical residence (RES_{hyp}). This latter scenario was developed in consideration of continued residential development of the land in the vicinity of LLNL, a pattern of land use that is expected to continue. The final exposure scenario addresses potential exposure of a child in a hypothetical child daycare center (cdc). For each scenario, exposure locations and exposure durations were identified to yield analyses which pertain to an MEI. The MEI receptor locations were identified in **Section IV** (and shown on **Figure IV-2**). In summary, the MEI locations and exposure scenarios which we evaluated are:

- MEI_{awo} = An adult worker off site located in a commercial facility north of the DWTF

- MEI_{aos} = An adult worker on site (i.e., within the fence line of LLNL)

- $MEI_{RESreal}$ = An individual living at an existing residence east of LLNL

- MEI_{REShyp} = An individual living at a hypothetical residence located east of the DWTF in the region of maximum predicted concentrations of chemicals emitted from the DWTF

- MEI$_{cdc}$ = A youngster at a hypothetical child daycare center in the residential suburb southwest of the main entrance to LLNL.

V.3   Exposure Pathway Screening

The release of chemicals present in waste designated for treatment at the DWTF or the Area 612 Facility is a function of the

- Physical form of the waste stream (i.e., liquid, solid, or sludge)

- Physical properties of the chemical constituents

- Configuration of the treatment facilities.

All chemicals handled and treated at these facilities are assumed to either (1) volatilize, or (2) partition as particulates from waste streams, with eventual release to the atmosphere via the DWTF stack, the Building 612 stack, or directly from the DWTF and the Area 612 blending/transfer areas. Exposure pathways associated with these atmospheric releases are addressed in this section. No ground-level or sub-surface releases will occur during routine operation of these facilities, and no permanent bodies of surface water exist in the area of maximum impact (**Figure IV-2**). Therefore, no explicit consideration is given to potential exposures associated with contact with surface water, groundwater, or sub-surface soil. Due to the increasing urbanization of land in the vicinity of LLNL, we did not evaluate exposures related to the consumption of homegrown livestock or poultry or their products (i.e., meat, milk, eggs).

V.3.1 Exposure Pathways Associated with Releases from the DWTF Tank Farm, and the Area 612 Facility and the DWTF Blending/Transfer Areas

For the DWTF Tank Farm and the Area 612 Facility and the DWTF blending/transfer areas, analyses presented in the 1995 *Health Risk Assessment for Hazardous and Mixed Waste Management Units* (1995 HRA) (McDowell-Boyer *et al.*, 1995) determined that chemicals of concern released from these treatment units are sufficiently volatile and insoluble (i.e., all have a Henry's Law constant ≥ 1.0 Pa-m^3/mol) that inhalation will be the dominant route of exposure. In the 1995 HRA the relative importance of alternative exposure pathways was evaluated using the analytical computer spreadsheet model, *CAirTOX* (McKone, 1993)**.** *CAirTOX* was developed for the state of California Air Resources Board (CARB) and the Office of Environmental Health Hazard Assessment (OEHHA) of the California Environmental Protection Agency (CAL/EPA) as a tool for determining the environmental fate of chemicals released into air and potential human doses. In that assessment, *CAirTOX* was used to screen the chemicals of concern on the basis of categories of Henry's Law constants ≥ 1.0 Pa-m^3/mol (e.g., approximately 1.0, 10, 100, and 1000 Pa-m^3/mol), and to demonstrate that for the chemicals with Henry's Law constants ≥ 1.0 Pa-m^3/mol, the inhalation exposure pathway dominates all others overwhelmingly. The representative Henry's Law constants and associated chemicals of concern used for this exposure pathway screening evaluation by *CAirTOX* were:

- 1.1 Pa-m^3/mol for methyl ethyl ketone

- 1.4 Pa-m^3/mol for methanol

- 12 Pa-m^3/mol for ethylene oxide

- 99 Pa-m^3/mol for 1,2-dichloroethane

- 440 Pa-m^3/mol for chloroform

- 1,500 Pa-m^3/mol for tetrachloroethylene.

The distribution of exposure and dose predicted by *CAirTOX* for the representative Henry's Law constants and associated chemicals of concern were obtained using landscape characteristics for the LLNL's Main Site (McDowell-Boyer *et al.*, 1995), and default parameters for human anatomical, dietary, and behavioral properties appearing in McKone (1993). The chemical-specific properties that define the intermedia transfer for these chemicals of concern were either developed using the methods described by McKone *et al.* (1993) for this purpose or, if provided, taken directly from McKone *et al.* (1993).

As presented in the 1995 HRA, *CAirTOX* revealed that for the chemicals of concern with Henry's Law constants $\geq$ 1.0, 10, 100, or 1000 Pa-m^3/mol, more than 99.5% of the dose can be attributed to inhalation exposure. Thus, the carcinogenic risk and noncarcinogenic hazard also will be dominated by inhalation exposure. As a consequence of this exposure pathway screening analysis, all other pathways of exposure (e.g., ingestion of food and water, or dermal exposure in showering) can be eliminated from further consideration because their contribution to dose is inconsequential relative to inhalation exposure. This result is empirically consistent with the fact that these chemicals are sufficiently volatile and relatively insoluble so as not to partition significantly to other environmental media after being released into the air. Therefore, we can generalize this conclusion to the chemicals identified to be of concern from the DWTF Tank Farm and the Area 612 Facility blending/transfer area.

Because it is anticipated that the DWTF blending/transfer area will handle waste streams and chemicals of concern identical in both nature and physical form to those handled at the Area 612 Facility blending/transfer area, we conclude that inhalation is also the dominant exposure pathway associated with releases from this waste treatment area.

V.3.2 Exposure Pathways Associated with Releases from Other Waste Treatment Units

For those waste treatment units designated to handle liquid waste streams (i.e., the centrifuge, filtration module, or the uranium bleaching unit), we assume that only volatile liquids will partition from these wastes for eventual release to the atmosphere (**Section III**). We further assume that treatment units which will handle waste solids or sludges (the solidification system; debris washer; shredder/chopper; Size Reduction Unit; and amalgamation, water, and pressure reactor units) will result in releases of both volatile and particulate chemicals to the atmosphere (**Section III**). In this section we describe a screening approach to identify the exposure

pathway(s) associated with the releases that are expected to result in the greatest contribution to dose, incremental cancer risk, and noncancer hazard. That approach is described here.

Both volatile and particulate contaminants are released from the DWTF and the Building 612 stacks directly into the atmosphere. Once in the atmosphere, these chemicals can be inhaled directly from air or deposited on soil. Humans may then be exposed by (1) direct inhalation of chemicals in air, (2) dermal absorption subsequent to contact with the soil, (3) incidental direct ingestion of contaminated soil, (4) inhalation of chemicals deposited on the soil and resuspended to air, or (5) deposition of chemicals onto the surface of homegrown produce with subsequent direct ingestion. In the following sections, we develop factors which characterize the intermedia transfer (partitioning) of chemicals from air to each exposure medium. We then derive pathway exposure factors (PEFs), based on physiological, anatomical, and lifestyle parameters, for each exposure medium and pathway. The product of each transfer factor and PEF provide the basis for the identification of dominant exposure pathways.

V.4   Derivation of Intermedia Transfer Factors for Characterizing Dominant Exposure Pathways

V.4.1 Transfer to Air

Chemicals emitted to the atmosphere subsequent to volatilization or release as particulates from wastes are available for direct inhalation without additional partitioning or intermedia transfer. For this exposure medium, the transfer factor, T_a, is equal to 1.0.

V.4.2 Transfer from Air to Vegetation

Chemicals present in air as particulates or volatile material can transfer directly by deposition to the surface of homegrown produce (i.e., fruits and vegetables). The equation which describes the transfer T of particulates p from air to vegetables v, T_{pv} (McKone and Daniels, 1991), is:

$$T_{pv} = \frac{0.47 \times \left(V_{dp} f_v\right)}{M_f R_v} \tag{V-1}$$

where:

0.47   = The fraction of the total mass of ingested homegrown fruits and vegetables that consist of unprotected produce or leafy vegetables;

V_{dp} = The deposition factor of atmospheric particulates onto food crops, 500 meters per day (m/d);

f_v = The fraction of the target population's vegetables, fruits, and grains that come from the area affected by the DWTF and the Area 612 Facility, assumed to be 1.0;

M_f = The annual average inventory of food crops per unit area, 3.0 kg fresh mass per m^2;

R_v = The weathering rate constant for atmospheric particulates, 0.03 d^{-1}.

Similarly, the transfer T of volatile (gaseous) chemicals g from air to homegrown produce v, T_{gv} (McKone and Daniels, 1991), is:

$$T_{gv} = \frac{0.47 \times 10^{-3} \times RT}{H(0.9 + 0.1K_{ow})} \qquad\qquad \text{(V-2)}$$

where:

0.47 = The fraction of the total mass of ingested homegrown fruits and vegetables (i.e., unprotected produce or leafy vegetables);

10^{-3} (m^3/kg) = A unit conversion factor;

R = The gas constant, 62.4 torr•L/mol•K;

K = The temperature, 2930° Kelvin;

H = Henry's Law constant, torr•L/mol; and

K_{ow} = The octanol-water partition coefficient.

For screening purposes, we selected a single value of H (7.6 torr•L/mol), which was applied to all volatile chemicals. This value was selected based on the *Preliminary Endangerment Assessment (PEA) Guidance Manual* (CAL/EPA/Department of Toxic Substances Control [DTSC], 1994), which defines volatile chemicals as those with a Henry's Law constant of 1×10^{-5} (atm•m^3/mol, which is equivalent to 7.6 torr•L/mol) or greater. Utilization of a single H value at the lower threshold of volatility maximizes the amount of volatile chemical calculated to partition from air to the surface of produce.

We also utilized a single value of K_{ow} in our screening calculations. As shown in **Figure V-1**, this value was identified by constructing a log-probability distribution of all values of K_{ow} listed in Table 1 of the *PEA Guidance Manual* (CAL/EPA/DTSC, 1994). This table lists K_{ow}s (and other chemical property data) for 169 volatile chemicals. We selected the 50th-percentile value of this distribution, $K_{ow} = 100$, as a representative description of the partitioning potential of volatile materials onto plants from air. Making the appropriate substitutions into **Equation V-1** and **Equation V-2** yields a value for T_{pv} of 2.61×10^3 (m^3/kg), and for T_{gv}, a value of 1.23×10^1 (m^3/kg).

V.4.3 Transfer from Air to Soil

The transfer T and subsequent accumulation of volatile (gaseous) chemicals g onto soil s, T_{gs}, can be estimated by:

$$T_{gs} = D_g \times \frac{1}{A15y} \times \frac{1}{\rho} \tag{V-3}$$

where:

D_g = Deposition rate of gaseous contaminants onto soil, 2.19×10^5 (meters/year) (McKone and Daniels, 1991);

A = Depth of accumulation in soil, 0.15 m (U.S. Nuclear Regulatory Commission [NRC], 1977);

$15y$ = The period of time contaminants are assumed to accumulate in soil (NRC, 1977); and

ρ = Soil bulk density, 2.0×10^3 (kg/m^3) (U.S. Environmental Protection Agency [EPA], 1988).

The transfer of particulates from air to soil, T_{ps}, and the associated accumulation can be estimated by replacing the term D_g in **Equation V-3** with a term for the deposition rate D of particulates p onto soil, D_p, of 1.83×10^5 (m/y) (McKone and Daniels, 1991). The calculated values of T_{gs} and T_{ps} are 1.1×10^4 (m^3/kg) and 9.1×10^3 (m^3/kg), respectively.

V.4.4 Transfer from Soil to Air (Resuspension)

We used a mass loading approach to estimate the magnitude of transfer of contaminants in surface soil to airborne soil particles. With this method, the amount of contaminant transferred to resuspended soil is calculated as the product of the transfer factor for volatile or particulate contaminants from air to soil (T_{gs} or T_{ps}) and the concentration of total suspended particulates TSP:

$$T_{gsr} = T_{gs} \times TSP \tag{V-4}$$

$$T_{psr} = T_{ps} \times TSP \tag{V-5}$$

where:

T_{gsr} = The factor which relates the transfer T of volatile (gaseous) contaminants g in surface soil s to airborne, resuspended particulates r;

T_{psr} = The corresponding factor which relates the transfer of particulate contaminants p in surface soil s to airborne, resuspended particulates r;

TSP = The concentration of total suspended particulates, 9.8×10^{-8} (kg [particulates]/m^3 [air]) (Bidleman, 1988).

Substituting the appropriate values in **Equations V-4** and **V-5** yields a value of 1.1×10^{-3} for T_{gsr}, and a value of 8.9×10^{-4} for T_{psr} (both values are dimensionless).

V.5 Derivation of the Pathway Exposure Factors for Characterizing Dominant Exposure Pathways

Pathway exposure factors (PEFs) incorporate information on physiology, anatomy, residence patterns, and assumptions on exposure frequency and exposure duration into an equation which, in combination with an intermedia transfer factor (see above) and a predicted environmental concentration of chemical, yields a lifetime-equivalent, chronic daily dose. In this section, we develop PEFs for seven exposure pathways:

- Direct inhalation;

- Ingestion of homegrown produce contaminated with volatile (gaseous) contaminants;

- Ingestion of homegrown produce contaminated with particulate chemicals;

- Dermal absorption subsequent to direct contact with contaminated soil;

- Incidental direct ingestion of contaminated soil;

- Inhalation of resuspended particulates contaminated with volatile (gaseous) contaminants; and

- Inhalation of resuspended particulates contaminated with particulate chemicals.

To characterize the dominant exposure pathways associated with releases from the DWTF and Area 612 Facility, we first derive PEFs applicable to an MEI$_{RES}$, where exposures are associated with an incremental risk of cancer. These PEFs are used in conjunction with intermedia transfer factors to identify those environmental media and exposure pathways which yield the principal contributions to human exposure. Subsequent to the identification of these dominant exposure pathways, we derive the relevant PEFs for an MEI$_{RES}$ exposed to noncarcinogenic contaminants as well as the applicable PEFs for the MEI$_{aos}$, MEI$_{awo}$, and MEI$_{cdc}$ exposure scenarios.

V.5.1 Pathway Exposure Factors for a Maximally Exposed Individual Resident, MEI$_{RES}$

The *PEA Guidance Manual* (CAL/EPA/DTSC, 1994) indicates that the period of exposure for the MEI at a residence should be 30 years from birth. For purposes of these calculations, we considered the first 6 years of life "childhood," *c*, and the remaining 24 years "adulthood," *a*, for

an MEI_{RES}. All other parameters presented in the following equations are from the EPA (1991) unless otherwise noted.

The PEF for direct inhalation of carcinogenic contaminants by an MEI_{RES} is:

$$RES - F_{ia,risk} = \left[\left(\frac{I_c}{BW_c} \times \frac{EF_{res} \times ED_c}{AT_{c,r}} \right) + \left(\frac{I_a}{BW_a} \times \frac{EF_{res} \times ED_a}{AT_{a,r}} \right) \right] \qquad \text{(V-6)}$$

where:

RES–$F_{ia,risk}$ = The pathway exposure factor F for direct inhalation i of contaminants in air a by an individual resident RES, where exposure is associated with a risk of cancer. The value of this PEF is 1.49×10^{-1} (m^3/kg•d).

I_c = A conservative estimate of the inhalation rate for a child (10 m^3/d);

BW_c = The body weight assumed for a child (15 kg);

EF_{res} = Exposure frequency corresponding to the time spent annually at a residence (350 days per year);

ED_c = Exposure duration for a child, assumed to be equal to the length of childhood (6 years);

$AT_{c,r}$ = Averaging time for computing risk for the childhood component of exposure, set equal to the number of days in a 70-year lifetime (25,550 days);

I_a = A conservative estimate of the inhalation rate of an adult (20 m^3/d);

BW_a = The body weight assumed for an adult (70 kg);

ED_a = Exposure duration for an adult, assumed to be equal to the length of adulthood at the MEI_{RES} location (24 years); and

$AT_{a,r}$ = Averaging time for computing risk for the adult component of exposure, set equal to the number of days in a 70-year lifetime (25,550 days).

The PEF (F) for ingestion by an individual resident RES of homegrown produce v contaminated with carcinogenic, gaseous chemicals g (RES–$F_{gv,risk}$) is equal to 9.07×10^{-4} (kg/kg•d). That value is obtained from the equation:

$$RES - F_{gv,risk} = \left[\left(\frac{I_{gv,c}}{BW_c} \times \frac{EF_{res} \times ED_c}{AT_{c,r}} \right) + \left(\frac{I_{gv,a}}{BW_a} \times \frac{EF_{res} \times ED_a}{AT_{a,r}} \right) \right] \qquad \text{(V-7)}$$

where:

$I_{gv,c}$ = The ingestion rate I of homegrown vegetables and other produce v contaminated with gaseous chemicals g ingested by a child c. This rate is equal to 6.10×10^{-2} (kg/d), based on the assumption that children eat one-half the amount of homegrown produce as do adults (see below).

$I_{gv,a}$ = The ingestion rate I, for an adult a of homegrown produce v contaminated with gaseous chemicals g which is equal to 1.22×10^{-1} (kg/d). This quantity is based on an assumption that the consumption of fruit is equal to 140 grams per day (g/d), the consumption of vegetables is equal to 200 g/d, and that the proportion of produce which is homegrown is equal to 30 percent for fruit and 40 percent for vegetables. The values for BW_c, EF_{res}, ED_c, $AT_{c,r}$, BW_a, ED_a, and $AT_{a,r}$ are identical to those given for **Equation V–6**.

The PEF (F) which accounts for ingestion by an individual resident RES of homegrown produce v contaminated with carcinogenic chemical particulates p, $RES–F_{pv,risk}$, is identical to $RES–F_{gv,risk}$ and is equal to 9.07×10^{-4} (kg/kg•d).

The PEF (F) for direct incidental ingestion in by an individual resident RES of carcinogenic gaseous contaminants g present in soil, $RES–F_{ing,risk}$, is equal to 1.57×10^{-6} (kg/kg•d). This PEF is described by **Equation V-8**:

$$RES - F_{ing,risk} = \left[\left(\frac{I_{inc}}{BW_c} \times \frac{EF_{res} \times ED_c}{AT_{c,r}} \right) \right] + \left[\left(\frac{I_{ina}}{BW_a} \times \frac{EF_{res} \times ED_a}{AT_{a,r}} \right) \right] \qquad \text{(V-8)}$$

where:

I_{inc} = The rate of direct incidental ingestion of contaminated soil by a child c 2.0×10^{-4} (kg/d), and

I_{ina} = The corresponding rate for an adult 1.0×10^{-4} (kg/d).

The values for BW_c, EF_{res}, ED_c, $AT_{c,r}$, BW_a, ED_a, and $AT_{a,r}$ are identical to those given for **Equation V–6**. The corresponding PEF for incidental ingestion in of soil contaminated with particulates p, $RES–F_{inp,risk}$, is numerically identical to $RES–F_{ing,risk}$ (1.57×10^{-6} [kg/kg•d]).

Dermal absorption of carcinogenic gaseous g contaminants from soil s by an individual resident RES ($RES-F_{gs,risk}$) is based on the relationship:

$$RES - F_{gs,risk} = \left[\left(\frac{D_{gs,c}}{BW_c} \times \frac{EF_{res} \times ED_c}{AT_{c,r}} \right) + \left(\frac{D_{gs,a}}{BW_a} \times \frac{EF_{res} \times ED_a}{AT_{a,r}} \right) \right] \qquad \text{(V-9)}$$

$D_{gs,c}$ is the dermal absorption rate D of gaseous g contaminants from soil s for a child c, 4.43×10^{-4} (kg/d). That value represents the product of (1) a soil adherence factor of

1×10^{-6} (kg/cm^2•d) (EPA, 1992); (2) a default absorption fraction, 0.15, which is specifically applicable to the fraction of polynuclear aromatic hydrocarbons absorbed across the skin (CAL/EPA/DTSC, 1994); and (3) 41% of the median total body surface area, 7200 cm^2, of a male child between 3 and 6 years of age (2952 cm^2) (EPA, 1990). The term $D_{gs,a}$ is analogous to $D_{gs,c}$ except that it is applicable to an adult a, and is equal to 3.03×10^{-4} (kg/d). This value is calculated as described for the term $D_{gs,c}$, with the difference that we consider the surface area of skin on the exposed head and hands of an adult male, 1.02×10^3 cm^2, instead of the relevant surface area of a child. The values for BW_c, EF_{res}, ED_c, $AT_{c,r}$, BW_a, ED_a, and $AT_{a,r}$ are identical to those given in **Equation V-6**. Making the appropriate substitutions in **Equation V-9** yields a value for $RES{-}F_{gs,risk}$ of 3.85×10^{-6} (kg/kg•d). The PEF for dermal absorption by an individual resident of carcinogenic chemicals present as particulates in soil, $RES–F_{PS,risk}$, is identical to $RES{-}F_{gs,risk}$ (3.85×10^{-6} [kg/kg•d]).

The PEFs (F) which account for the inhalation i of gaseous g or particulate p contaminants deposited on soil s and resuspended r as airborne contaminants are identical to those previously described for the direct inhalation of contaminants in air:

$$RES–F_{igsr,risk} = 1.49 \times 10^{-1} \ (m^3/kg•d)$$

$$RES–F_{ipsr,risk} = 1.49 \times 10^{-1} \ (m^3/kg•d)$$

To identify those environmental media and exposure pathways which are expected to yield the dominant contribution to dose, we calculated the product of each intermedia transfer factor and each appropriate PEF (**Table V-1**). These calculations were completed only for the MEI$_{RES}$ PEFs developed for exposure to carcinogens. We did not make parallel calculations based on PEFs for the MEI$_{aos}$, MEI$_{awo}$, or MEI$_{cdc}$, because, relative to these scenarios, the MEI$_{RES}$ PEFs yield upper-bound estimates of exposure magnitude.

The values presented in **Table V-1** indicate that direct inhalation of contaminants from air (TF•PEF product = 1.49×10^{-1} (m^3/kg•d) and ingestion of homegrown produce contaminated with particulates (TF•PEF product = 2.36 [kg/kg•d]) are 1 to 4 orders of magnitude greater than other TF•PEF products. As a consequence of this numerical difference, these exposure pathways are expected to contribute most significantly to total exposure (dose), risk, and hazard. On the basis of this exposure pathway screening comparison, we selected direct inhalation of contaminants from air and ingestion of homegrown produce contaminated with chemical particulates as the two exposure pathways appropriate for quantitative evaluation of both risk and noncancer hazard associated with releases from the DWTF and the Area 612 Facility. All other pathways of exposure were eliminated from further consideration because their contributions to dose are not expected to be significant.

V.6 Characterization of Pathway Exposure Factors for an MEI$_{RES}$ Exposed to Noncarcinogenic Contaminants

Based on the exposure pathway screening just presented, we determined that there are two relevant PEFs for an MEI$_{RES}$ potentially exposed to noncarcinogenic chemicals released from the DWTF and Area 612 Facility. The first of these is a PEF (F) which accounts for exposure of an MEI$_{RES}$ by direct inhalation i of airborne a noncarcinogenic chemicals, $RES\text{-}F_{ia,hazard}$. The value of this PEF, 9.13×10^{-1} (m^3/kg•d), can be obtained by substituting the term $AT_{c,h}$ (averaging time for hazard [h], childhood [c] exposure [2190 days]), and the term $AT_{a,h}$ (averaging time for hazard [h], adult [a] exposure [8760 days]) for the terms $AT_{c,r}$ and $AT_{a,r}$ respectively, in **Equation V–6**.

The second PEF (F) of interest is used to characterize the noncancer hazard from ingestion of homegrown produce v contaminated with chemical particulates p. The value of this PEF, 5.6×10^{-3} (kg/kg•d) ($RES\text{–}F_{pv,hazard}$) can be calculated by substituting the terms $AT_{c,h}$ (2190 days) and $AT_{a,h}$ (8760 days) for $AT_{c,r}$ and $AT_{a,r}$ respectively, in **Equation V–7**. Note that for particulate contaminants, the terms $I_{pv,c}$ and $I_{pv,a}$ (ingestion I of homegrown vegetables v contaminated with particulate chemicals p), replace the terms $I_{gv,c}$ and $I_{gv,a}$ in **Equation V-7**. However, the value of the terms for particulate contaminants are numerically identical to the value of the terms derived for gaseous contaminants.

V.7 Characterization of Exposure Pathways for the MEI$_{aos}$ and MEI$_{awo}$

The assessment of chronic daily intake (dose) to the MEI$_{aos}$ and MEI$_{awo}$ considers only exposures which occur during employment as an adult, and incorporates an exposure frequency and an exposure duration which correspond to representative upper-bound occupational periods (EPA, 1991). For both the MEI$_{aos}$ and MEI$_{awo}$, we evaluate exposures which occur by direct inhalation. The PEF (F) for direct inhalation i of carcinogenic contaminants in air a by an individual adult worker is described by the relation:

$$AOS, AWO - F_{ia,risk} = \left[\frac{I_a}{BW_a} \times \frac{EF_{aos,awo} \times ED_{aos,awo}}{AT_r} \right] \tag{V-10}$$

The PEF for direct inhalation of noncarcinogenic contaminants in air by an individual worker is:

$$AOS, AWO - F_{ia,hazard} = \left[\frac{I_a}{BW_a} \times \frac{EF_{aos,awo} \times ED_{aos,awo}}{AT_h} \right] \tag{V-11}$$

The terms I_a and BW_a were defined previously. We selected an exposure frequency ($EF_{aos,awo}$) equal to 2000 hours per year (based on 8 hours per day, 5 days per week, 50 weeks per year) and an exposure duration ($ED_{aos,awo}$) equal to 25 years. Averaging time AT for exposure to carcinogens AT_r is set equal to 613,200 days (the number of days in a 70-year lifetime) or to 219,000 days for exposure to noncarcinogens (AT_h) (the number of days in 25 years). Making the appropriate substitutions to **Equation V-10** and **Equation V-11** yields a value for *AOS,*

AWO–$F_{ia,risk}$ of 2.33×10^{-2} (m^3/kg•d); and a value of *AOS, AWO*–$F_{ia,\,hazard}$ of 6.52×10^{-2} (m^3/kg•d).

At LLNL there is an employee-maintained garden used solely for recreational purposes, which could supply an MEI$_{aos}$ with contaminated, "homegrown" produce. Accordingly, we evaluated potential exposures from this pathway for an MEI$_{aos}$. The PEF (F) associated with ingestion of vegetables *v* contaminated with carcinogenic particulates *p* is:

$$AOS - F_{pv,risk} = \left[\frac{I_{pv,a}}{BW_a} \times \frac{EF_{aos} \times ED_{aos}}{AT_r} \right] \qquad \text{(V-12)}$$

$I_{pv,a}$, BW_a, and AT_r were defined previously; EF_{aos} and ED_{aos} are numerically identical to $EF_{aos,awo}$ and $ED_{aos,awo}$, respectively (defined above). Substituting the appropriate values into **Equation V-12** yields the value for AOS–$F_{pv,risk}$ of 1.42×10^{-4} (kg/kg•d). The corresponding PEF which characterizes exposure to noncarcinogenic particulates, AOS–$F_{pv,hazard}$, can be obtained by substituting AT_h for AT_r in **Equation V-12**. This substitution yields a value of 3.98×10^{-4} (kg/kg•d).

V.8   Characterization of Exposure Pathways for MEI$_{cdc}$

Children attending a hypothetical child daycare center at a residence southwest of LLNL are considered to receive exposures only by direct inhalation. Accordingly, the PEFs for these receptors can be described by:

$$CDC - F_{ia,risk} = \left(\frac{I_c}{BW_c} \times \frac{EF_{cdc} \times ED_c}{AT_{c,r}} \right) \qquad \text{(V-13)}$$

and

$$CDC - F_{ia,hazard} = \left(\frac{I_c}{BW_c} \times \frac{EF_{cdc} \times ED_c}{AT_{c,h}} \right) \qquad \text{(V-14)}$$

where CDC–$F_{ia,risk}$ is the factor *F* which characterizes exposures of children at a daycare center (cdc) by direct inhalation *i* of contaminants in air *a* (**Equation V-13**). CDC–$F_{ia,hazard}$ is the corresponding PEF for noncarcinogenic exposures (**Equation V-14**). The terms I_c, BW_c, ED_c, $AT_{c,r}$, and $AT_{c,h}$ have been defined previously, and EF_{cdc} is equal to 2000 hours per year. The values of these PEFs are 1.3×10^{-2} (m^3/kg•d) and 1.52×10^{-2} (m^3/kg•d), respectively.

V.9   References

Bidleman, T.F. 1988. "Atmospheric Processes," *Environ. Sci. Technol.* 22: 361-367.

California Air Resources Board and California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CARB and OEHHA). 1992. *Health Risk*

Assessment Program, Version 1.1, Project Assessment Branch, Stationary Source Division, California Air Resources Board, Sacramento, CA.

California Environmental Protection Agency, Department of Toxic Substances Control (CAL/EPA/DTSC). 1994. *Preliminary Endangerment Assessment (PEA) Guidance Manual.* California Environmental Protection Agency, Department of Toxic Substances Control, Sacramento, CA, January.

McDowell-Boyer, L.; J. Daniels; G. Gallegos; F. Gouveia; L. Hall; G. May; T. Kato; J. Huang; and A. Dennis. 1995. *Health Risk Assessment for Hazardous and Mixed Waste Management Units at Lawrence Livermore National Laboratory, 1995.* (1995 Health Risk Assessment [HRA]). Lawrence Livermore National Laboratory, Livermore, CA, November, UCRL-AR-119482.

McKone, T.E. and J.I. Daniels. 1991. "Estimating Human Exposure through Multiple Pathways from Air, Water, and Soil." *Regulatory Toxicology and Pharmacology* . 13:36-61.

McKone, T.E. 1993. *CAirTOX: A Compartment Model for Assessing the Fate of and Human Exposure to Toxic-Chemical Emissions to Air.* Prepared for State of California Air Resources Board and California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Lawrence Livermore National Laboratory, Livermore, CA, October, UCRL-CR-115619.

McKone, T.E., J.I. Daniels, F.F Chiao, and D.P.H. Hsieh. 1993. *Intermedia Transfer Factors for Fifteen Toxic Pollutants Released to Air Basins in California.* Prepared for State of California Air Resources Board and California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Lawrence Livermore National Laboratory, Livermore, CA, October, UCRL-CR-115620.

U.S. Environmental Protection Agency. 1988. *Superfund Exposure Assessment Manual.* U.S. Environmental Protection Agency, Office of Remedial Response, Washington, D.C., EPA/540/1-88/001.

U.S. Environmental Protection Agency. 1990. *Exposure Factors Handbook.* U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Washington, D.C., EPA 600-8-89-043.

U. S. Environmental Protection Agency. 1991. *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual, Supplemental Guidance* "Standard Default Exposure Factors," Interim Final. Office of Emergency and Remedial Response, Toxics Integration Branch, U. S. Environmental Protection Agency, Washington, D.C., OSWER Directive: 9285.6-03.

U.S. Environmental Protection Agency. 1992. *Dermal Exposure Assessment: Principles and Applications.* U.S. Environmental Protection Agency, Exposure Assessment Group, Washington, D.C., EPA/600/8-91/011B, Interim Report.

U.S. Nuclear Regulatory Commission (NRC). 1977. *Regulatory Guide 1.109. Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix 1, Revision 1.* U.S. Nuclear Regulatory Commission, Washington, D.C.

V.10 Acronyms

aos	Adult worker off site
awo	Adult worker on site
CAL/EPA	California Environmental Protection Agency
CARB	California Air Resources Board
cdc	child daycare center
DOE	U.S. Department of Energy
DTSC	Department of Toxic Substances Control
DWTF	Decontamination and Waste Treatment Facility
EPA	U.S. Environmental Protection Agency
HRA	Health Risk Assessment
LLNL	Lawrence Livermore National Laboratory
MEI	Maximally exposed individual
NRC	U.S. Nuclear Regulatory Commission
OEHHA	Office of Environmental Health Hazard Assessment
PEA	Preliminary Endangerment Assessment
PEF	Pathway exposure factor
RES_{hyp}	Residence (hypothetical)
RES_{real}	Residence (real)
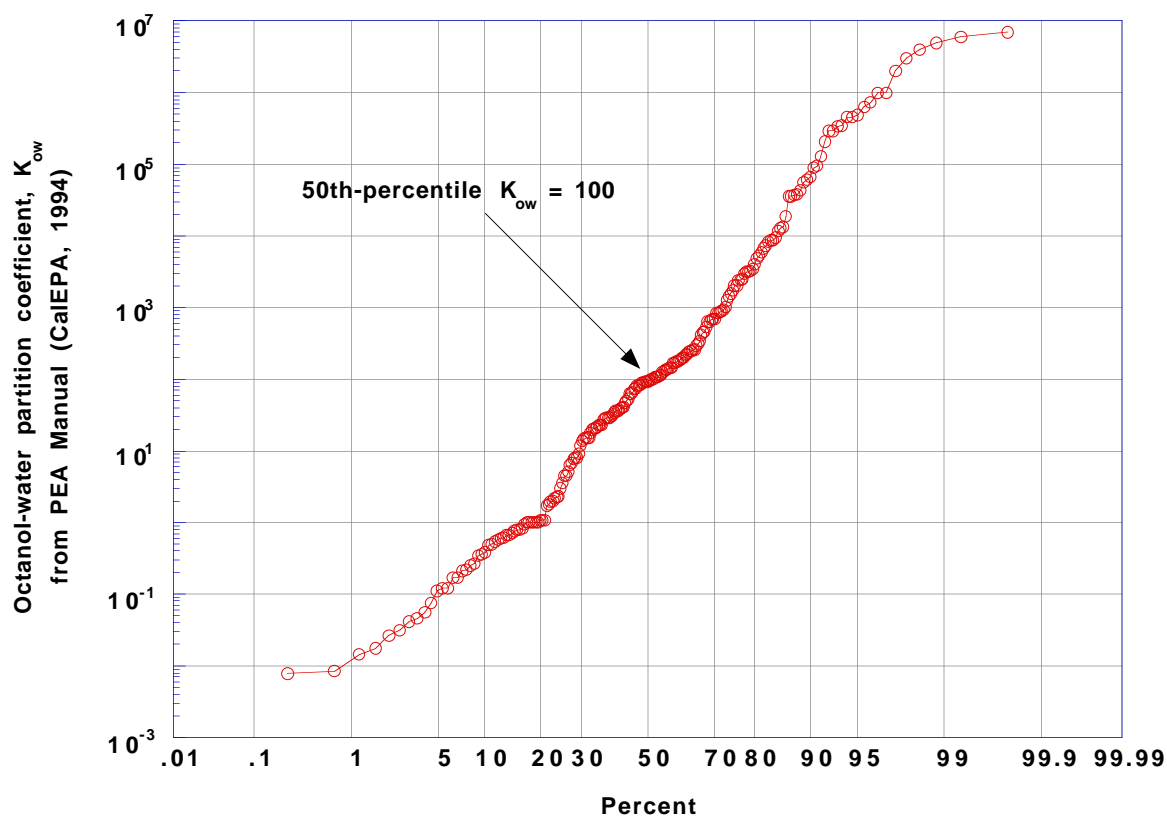
Figure V-1. Log-probability plot distribution of all values of K_{ow} obtained from the *PEA Guidance Manual* (CAL/EPA/DTSC, 1994)

Table V-1. Screening matrix of intermedia transfer factors, pathway exposures factors and their products

Intermedia Transfer Factor (TF)	Pathway Exposure Factor (PEF)	Product of TF and PEF
T_a, 1.0	RES-$F_{ia,risk}$, 1.49×10^{-1} (m³/kg•d)	1.49×10^{-1} (m³/kg•d)[a]
T_{pv}, 2.61×10^3 (m³/kg)	RES-$F_{pv,risk}$, 9.07×10^{-4} (kg/kg•d)	2.36 (kg/kg•d)[a]
T_{gv}, 1.23×10^1 (m³/kg)	RES-$F_{gv,risk}$, 9.07×10^{-4} (kg/kg•d)	1.12×10^{-2} (kg/kg•d)
T_{ps}, 9.1×10^3 (m³/kg)	RES-$F_{ps,risk}$, 3.85×10^{-6} (kg/kg•d)	3.50×10^{-2} (kg/kg•d)
	RES-$F_{inp,risk}$, 1.57×10^{-6} (kg/kg•d)	1.43×10^{-2} (kg/kg•d)
T_{gs}, 1.1×10^4 (m³/kg)	RES-$F_{gs,risk}$, 3.85×10^{-6} (kg/kg•d)	4.23×10^{-2} (kg/kg•d)
	RES-$F_{ing,risk}$, 1.57×10^{-6} (kg/kg•d)	1.73×10^{-2} (kg/kg•d)
T_{gsr}, 1.07×10^{-3} (dimensionless)	RES-$F_{igsr,risk}$, 1.49×10^{-1} (m³/kg•d)	1.59×10^{-4} (m³/kg•d)
T_{psr}, 8.9×10^{-4} (dimensionless)	RES-$F_{ipsr,risk}$, 1.49×10^{-1} m³/kg•d)	1.33×10^{-4} (m³/kg•d)

[a]   Identified as a dominant exposure pathway.

Section VI.

Characterizing Toxicological Properties of Representative Chemicals for Carcinogenic Risk, Noncarcinogenic Hazard, and Reference Exposure Level

SECTION VI. CHARACTERIZING TOXICOLOGICAL PROPERTIES OF REPRESENTATIVE CHEMICALS FOR CARCINOGENIC RISK, NONCARCINOGENIC HAZARD, AND REFERENCE EXPOSURE LEVEL

VI.1 Introduction

This Section describes the procedures used to characterize the exposure pathway specific toxicological properties (i.e., carcinogenic-potency [slope] factors [CPFs], reference doses [RfDs], and/or reference exposure levels [RELs]) of the chemicals that represent those of concern at hazardous waste management facilities at the Main Site of Lawrence Livermore National Laboratory (LLNL). The chemical-specific toxicological values were selected from the regulatory literature according to the procedure recommended in the *Preliminary Endangerment Assessment (PEA) Guidance Manual* prepared by the California Environmental Protection Agency, Department of Toxic Substances Control (CAL/EPA/DTSC, 1994). However, for those substances for which chemical-specific toxicity data are not published in federal or state regulatory literature, and also for those substances that could only be categorized as "non-specific," we took the approach of estimating and assigning to each of these chemicals a reasonably conservative value for the pathway-specific CPFs, RfDs, and RELs. The applicable toxicity values described in this section will be combined in **Section VII** with:

1) the relevant products of pathway-exposure factors (PEFs) and intermedia-transfer factors (ITFs) discussed in **Section V** (and equating to exposure by direct inhalation and ingestion of homegrown produce);

2) location-specific χ/Q values from **Section IV**; and

3) the scaled annual emission rates for specific chemicals (expressed in kg/y) derived in **Section III**.

to obtain the location and corresponding estimated potential total carcinogenic risk and total indices of chronic and noncarcinogenic hazard for the maximally exposed individual in each receptor category (MEI_p; where p refers to a receptor represented by either an adult worker on site [aos] for 25 years, an adult worker off site [awo] for 25 years, a child at a daycare center [cdc] for the first 6 years of life, or an individual at an existing residence [RES_{real}] or a hypothetical one [RES_{hyp}] for the first 30 years of life). The calculations used to generate these results also will be described in **Section VII**. The product of these three terms is also used to estimate the 1-hour-acute, noncarcinogenic hazard at the location of the maximum, predicted concentration of the chemicals of concern.

VI.2 Assignment of Regulatory Names

As explained in **Section VI.1**, unique, standardized chemical names were assigned to each chemical name reported in the Hazardous Waste Management (HWM) database files (e.g., Total Waste Management System [TWMS]). However, for many of these unique, standardized chemical names, especially if they are mixtures, the analogous or appropriate chemical name that

appears in the regulatory literature, and for which there is toxicological information, is not identical.

VI.2.1 Individual chemicals

Consequently, for individual chemicals, we found it necessary to assign to the unique, standardized chemical name the appropriate, analogous specific, regulatory name and accompanying toxicological data. For example, all unique, standardized chemical names representing inorganic mercury compounds (e.g., mercury, mercury chloride, mercuric iodide, mercuric oxide, mercurous oxide, etc.) are assigned the specific regulatory name of "mercury (elemental)," and the toxicological information associated with that regulatory name is used.

VI.2.2 Chemical mixtures

Similarly, for two different chemical mixtures—volatile halogenated substances (VHS) and kerosene—reported in HWM database files it was necessary to assign specific regulatory names and associated toxicological data.

The first mixture involved the group of 29 chemicals that are each designated in the HWM database files as a VHS (see **Table VI-1**), (Grandfield, 1989). The applicable exposure pathway-specific CPFs, RFDs, and/or RELs were identified for each of the 29 substances designated as a VHS. These toxicological values were assigned according to the procedure recommended in the *PEA Guidance Manual* (CAL/EPA/DTSC, 1994) and described in the next part of this section. Next, the highest exposure pathway-specific CPF (2.7×10^{-1} [mg/kg-d]$^{-1}$), the lowest RfD (5.7×10^{-4} mg/kg-d), and the lowest REL (2.7×10^{-1} µg/m^3) were selected from the set of available values and used to estimate conservatively the incremental excess lifetime cancer risk and indices of noncancer hazard associated with the treatment of VHS. The highest CPF pertains to both vinyl chloride and 1,1,2,2-tetrachloroethane (CAL/EPA/Office of Environmental Health Hazards Assessment [OEHHA], 1994b), the lowest RfD pertains to carbon tetrachloride (EPA, Region IX, 1995), and the lowest REL is associated with vinyl chloride (California Air Pollution Control Officers Association [CAPCOA], 1993). (Calculated emissions of VHS from area sources at the Decontamination and Waste Treatment Facility (DWTF) and Area 612 were based on physical property data for vinyl chloride, which reflects the greater volatility and resulting higher emission rate of this chemical relative to 1,1,2,2-tetrachloroethane and carbon tetrachloride (see McDowell-Boyer *et al.*, 1995).

The composition of kerosene has been defined as "a mixture of petroleum hydrocarbons, chiefly of the methane series having from 10 to 16 carbon atoms per molecule" (Budavari, 1989). As described previously, these volatile compounds are generally going to be the ones contributing most to air pollution. A typical analysis of kerosene includes n-dodecane, alkylbenzenes, naphthalene, and 1- and 2-methyl tetrahydronaphthalene (Budavari, 1989). Naphthalene is the only chemical of this group that had quantitative information available from the regulatory sources of toxicity data used in this risk assessment (e.g., CAL/EPA/OEHHA, 1994a, 1994b, and 1995; EPA, Region IX, 1995; and CAPCOA, 1993). We made the assumption that the toxicity from exposure to naphthalene is representative of the potential adverse health effects from exposure to kerosene; therefore, we used the inhalation RfD of naphthalene (4.0×10^{-2} mg/kg-d

(Environmental Protection Agency [EPA], Region IX, 1995) to calculate noncarcinogenic health effects associated with the treatment of kerosene in waste treatment facilities at LLNL. No carcinogenic risk value was assigned in the regulatory literature to naphthalene, and an acute REL had not been derived.

VI.3 Determination of Cancer Potency (Slope) Factors (CPF) and Reference Doses (RfDs)

Chemical-specific CPF, RfD, and REL values were obtained from the regulatory literature in accordance with the approach recommended in the *PEA Guidance Manual* (CAL/EPA/DTSC, 1994). Specifically, the primary source for exposure pathway specific CPF values is a *Memorandum—California Cancer Potency Factors: Update* published by the state of California (CAL/EPA/OEHHA, 1994b) that identifies the inhalation and oral CPFs that are reported by the state of California for well over 200 substances. If the chemical of interest and associated CPFs do not appear in the state of California's 1994 *Memorandum*, then the Preliminary Remediation Goals (PRGs) developed by Region IX of the U.S. Environmental Protection Agency (EPA, Region IX, 1995) were consulted for such data. The PRGs were also the sole source for all exposure pathway specific RfDs. The CPFs are used in **Appendices F** and **F′**, and the RfDs are used in **Appendices G**, and **G′** in the determination of carcinogenic risk and noncarcinogenic hazard for each treatment unit.

Published exposure pathway specific CPFs were always applied accordingly for a specific chemical. However, if only a CPF for one exposure pathway exists for a chemical, then that published CPF was applied to all other exposure pathways of interest. For example, if only an oral CPF is reported for a specific chemical, then the oral CPF was applied to any other exposure pathway of interest (e.g., inhalation). Similarly, if there is an RfD for only one exposure pathway for a particular chemical, then that RfD was considered to be applicable to all other exposure pathways of interest for that chemical.

Chemicals for which there is at least one published CPF, but no RfD values (e.g., benzene), are first addressed in terms of their potential carcinogenic risk and then assigned surrogate RfDs for each of the exposure pathways of interest (the magnitude of this surrogate is explained in the next part of this section that focuses on development of surrogate RfDs). For those chemicals for which an RfD has been published but no CPF exists, there is no scientific basis for assuming such chemicals should be treated as carcinogenic. Therefore, these chemicals are evaluated only in terms of their noncarcinogenic hazard (represented by the reported RfD[s]).

VI.3.1 Addressing Non-toxic Chemicals and Development of Surrogate CPFs and RfDs for Chemicals Having No Published Toxicity Information

Chemicals that obviously are non-toxic have been designated as such (e.g., water, table salt, biological materials, such as proteins, etc.) and were eliminated from further consideration. However, chemicals for which there is no reported CPF or RfD in the regulatory literature that was examined, as well as chemicals that are classified as non-specific needed to be addressed toxiologically. Accordingly, these chemicals were assigned surrogate exposure pathway-specific CPFs and RfDs that are representative. This was done to compensate for the following

uncertainties. First, chemicals for which no CPF or RfD is reported could potentially contribute to total excess lifetime cancer risk and potential total noncancer hazard associated with the routine operation of waste treatment facilities at LLNL. Additionally, there are other sources of uncertainty that are attributable to: 1) the fact that the identity of constituents entering the waste treatment system do not remain static over time; and 2) it was not possible to make specific or comprehensive predictions concerning the identity of all possible waste constituents which may be treated or handled at LLNL in the future. Such waste constituents may include other substances identified by the Bay Area Air Quality Management District as Toxic Air Contaminants (TACs) (LLNL, 1995), other chemicals included in the EPA Hazardous Waste Codes (EPA, 1994) or state of California Hazardous Waste Codes (22 California Code of Regulations [CCR] 66261), and/or additional chemicals used in biomedical or other research that were not otherwise identified as TACs or by waste codes.

To characterize the potential cancer risk associated with emissions from a waste treatment stream that may have constituents not specifically addressed in the current estimates of risk and hazard, we constructed four log-probability distributions based on the inhalation and ingestion CPFs and RfDs reported by the state of California (CAL/EPA/OEHHA, 1994b) and by Region IX of the EPA (1995). These distributions appear in **Figure VI-1** through **Figure VI-4**.

VI.3.1.1   Surrogate CPFs

Figure VI-1 and **Figure VI-2** show the log-probability distributions for inhalation and oral CPFs. The distribution for oral CPFs was created using 300 values, and the distribution of inhalation CPFs was created using 306 values. These CPF values were obtained from the regulatory literature in the following manner. First, the *Memorandum* (CAL/EPA/OEHHA, 1994b) was examined to obtain oral and inhalation CPFs. Then, the PRGs (EPA, Region IX, 1995) were reviewed to obtain all of the RfDs and also those CPFs not contained in the *Memorandum*. Therefore, only one regulatory value for a CPF for a particular chemical was used in both **Figure VI-1** and **Figure VI-2**. The 50th-percentile CPF value of each distribution was used as the starting point for deriving each of the exposure pathway-specific surrogate CPFs. For each individual treatment unit, the 50th-percentile CPF value for a specific exposure pathway is then multiplied by the mass fraction of carcinogenic chemicals that will be treated by that unit (i.e., the quotient of the mass of chemicals with carcinogenic toxicity reported in the regulatory literature and the total mass of all chemicals, including the non-toxic and non-specific chemicals, to be treated by that particular waste treatment procedure, calculated in **Appendix C′**). These surrogate CPF values are used to estimate the contribution to the total potential excess lifetime cancer risk made by the chemicals identified as non-specific and the chemicals for which no toxicity data exist. The resulting contribution to the total potential excess lifetime cancer risk is considered reasonable because the 50th-percentile value is used. These 50th-percentile CPF values for the inhalation and oral exposure pathways are 0.4 and 0.7 mg/(kg•d)$^{-1}$, respectively.

VI.3.1.2   Surrogate RfDs

Figure VI-3 and **Figure VI-4** illustrate the log-probability distributions for inhalation and oral RfDs, respectively. The 50th-percentile RfD values selected from these distributions represent the respective surrogate RfDs. For the inhalation exposure pathway, the surrogate RfD is

0.01 mg/(kg•d) and was derived using the 479 inhalation RfD values reported in the PRGs (EPA, Region IX, 1995). For the oral exposure pathway, the surrogate RfD is also 0.01 mg/(kg•d) and was derived using the 429 oral RfD values reported in the PRGs (EPA, Region IX, 1995). Neither of these 50th-percentile RfD values is modified by an additional term (as was done for the derivation of the CPFs) because all chemicals without toxicity values are considered to possess some noncarcinogenic toxicity, and assigning the 50th-percentile RfD values to all chemicals for which no toxicity information is available in the prescribed regulatory literature is considered a conservative approach.

VI.4 Assignment of Reference Exposure Levels (RELs)

The acute reference exposure level (RELs) for a particular chemical is based generally on not exceeding the 1-hour ambient air concentration ($\mu g/m^3$) at breathing level that will produce the most sensitive, adverse health effect reported in the medical and toxicological literature and is defined by the state of California to be that 1-hour concentration ($\mu g/m^3$) at or below which no adverse health effects are anticipated in a member of the general public (CAPCOA, 1993). Only those chemicals for which RELs have been developed or are proposed by the state of California as part of the Air Toxics "Hot Spots" Program are taken into consideration. The RELs that are currently enforced are listed in the Revised 1992 *Risk Assessment Guidelines for the Air Toxics "Hot Spots" Program* (CAPCOA, 1993) and those that are proposed appear in the *Draft for Public Comment of the Evaluation of Acute Non-Cancer Health Effects for the Air Toxics Hot Spots Program* (CAL/EPA/OEHHA, 1994a) with more details regarding derivation contained in a companion document (CAL/EPA/OEHHA, 1995). These concentration limits are applied only to locations off the LLNL site. It is important to emphasize that, if an REL for a particular chemical is not listed in the published regulatory literature (CAPCOA, 1993; and CAL/EPA/OEHHA, 1994a and 1995), one was not developed. The RELs are used in **Appendix I** in the determination of 1-hour-acute, noncarcinogenic hazard for each treatment unit.

VI.5 References

Budavari, S., Ed. 1989. *The Merck Index, An Encyclopedia of Chemicals, Drugs, and Biologicals*. Eleventh Edition. Merck and Co., Rahway, NJ.

California Code of Regulations (CCR). Title 22, Part 66261, California Hazardous Waste Codes (22 CCR 66261).

California Air Pollution Control Officers Association (CAPCOA). 1993. *Air Toxics "Hot Spots" Program, Revised 1992 Risk Assessment Guidelines.* Toxics Committee of the California Air Pollution Control Officers Association, in consultation with the Air Toxicology Unit, Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment, and the Special Projects Section, Toxic Air Contaminant Identification Branch, Air Resources Board. Sacramento. CA, October.

California Environmental Protection Agency, Department of Toxic Substances Control (CAL/EPA/DTSC). 1994. *Preliminary Endangerment Assessment (PEA) Guidance Manual (A guidance manual for evaluating hazardous substances release sites).* California Environmental Protection Agency, Department of Toxic Substances Control, Sacramento, CA, January.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1994a. *Air Toxics "Hot Spots "Program Risk Assessment Guidelines: Part 1, Evaluation of Acute Non-Cancer Health Effects, Draft for Public Comment.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA, December.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1994b. *Memorandum—California Cancer Potency Factors: Update.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Standards and Criteria Work Group, Sacramento, November (update of the compilation of cancer potency factors issued originally in June 1992; the majority of which have undergone peer review and in many cases rigorous regulatory review).

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1995. *Technical Support Document* for *The Determination of Acute Toxicity Exposure Levels for Airborne Toxicants, Draft for Public Comment*. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA, January.

California Regional Water Quality Control Board (CAL/RWQCB). 1990. Regional Water Quality Control Board, Sacramento, CA.

Grandfield, C.H. 1989. *Guidelines for Discharges to the Sanitary Sewer System,* Lawrence Livermore National Laboratory, Livermore, CA, UCAR-10235.

McDowell-Boyer, L., J. Daniels, G. Gallegos, F. Gouveia, L. Hall, G. May, T. Kato, J. Huang, and A. Dennis, 1995. *Health Risk Assessment for Hazardous and Mixed Waste Management Units at Lawrence Livermore National Laboratory, 1995,* G. Cannon, Ed., Environmental Protection Department and Health and Ecological Assessment Division, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-AR-119482.

Lawrence Livermore National Laboratory. 1995. *Data Supporting the 1995 Health Risk Assessment for Hazardous and Mixed Waste Management Facilities at LLNL.* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-AR-122091.

Stoker, H.S., and S.L. Seager. 1976. *Environmental Chemistry: Air and Water Pollution.* Second Edition. Scott, Foresman, and Company, Glenview, IL.

U.S. Environmental Protection Agency, 1994. Title 40—Protection of Environment, Part 261—
    Identification and Listing of Hazardous Waste, Code of Federal Regulations (40 CFR 261),
    Office of the Federal Register National Archives and Records Administration, Reprinted by
    Bernan, Lanham, MD.

U.S. Environmental Protection Agency, Region IX (EPA, Region IX). 1995. *Preliminary
    Remediation Goals: PRG Concentrations, Version 3.2*. Technical Support Section, U.S.
    Environmental Protection Agency, Region IX, San Francisco, CA, September 1995.

VI.6 Acronyms

awo	adult worker on site
CAL/EPA	California Environmental Protection Agency
CAPCOA	California Air Pollution Control Officers Association
CCR	California Code of Regulations
cdc	child daycare center
CPF	carcinogenic-potency (slope) factors
DTSC	Department of Toxic Substances Control
DWTF	Decontamination and Waste Treatment Facility
EPA	U.S. Environmental Protection Agency
HWM	Hazardous Waste Management
ITF	Intermedia-transfer factor
LLNL	Lawrence Livermore National Laboratory
MEI	Maximally exposed individual
OEHHA	Office of Environmental Health Hazards Assessment
PEA	Preliminary Endangerment Assessment
PEF	Pathway exposure factor
PRG	Preliminary Remediation Goals
REL	Reference exposure levels

RES_{hyp} Residence (hypothetical)

RES_{real} Residence (real)

RfD   Reference dose

TAC   Toxic Air Contaminants

TWMS   Total Waste Management System

VHS   volatile halogenated substances
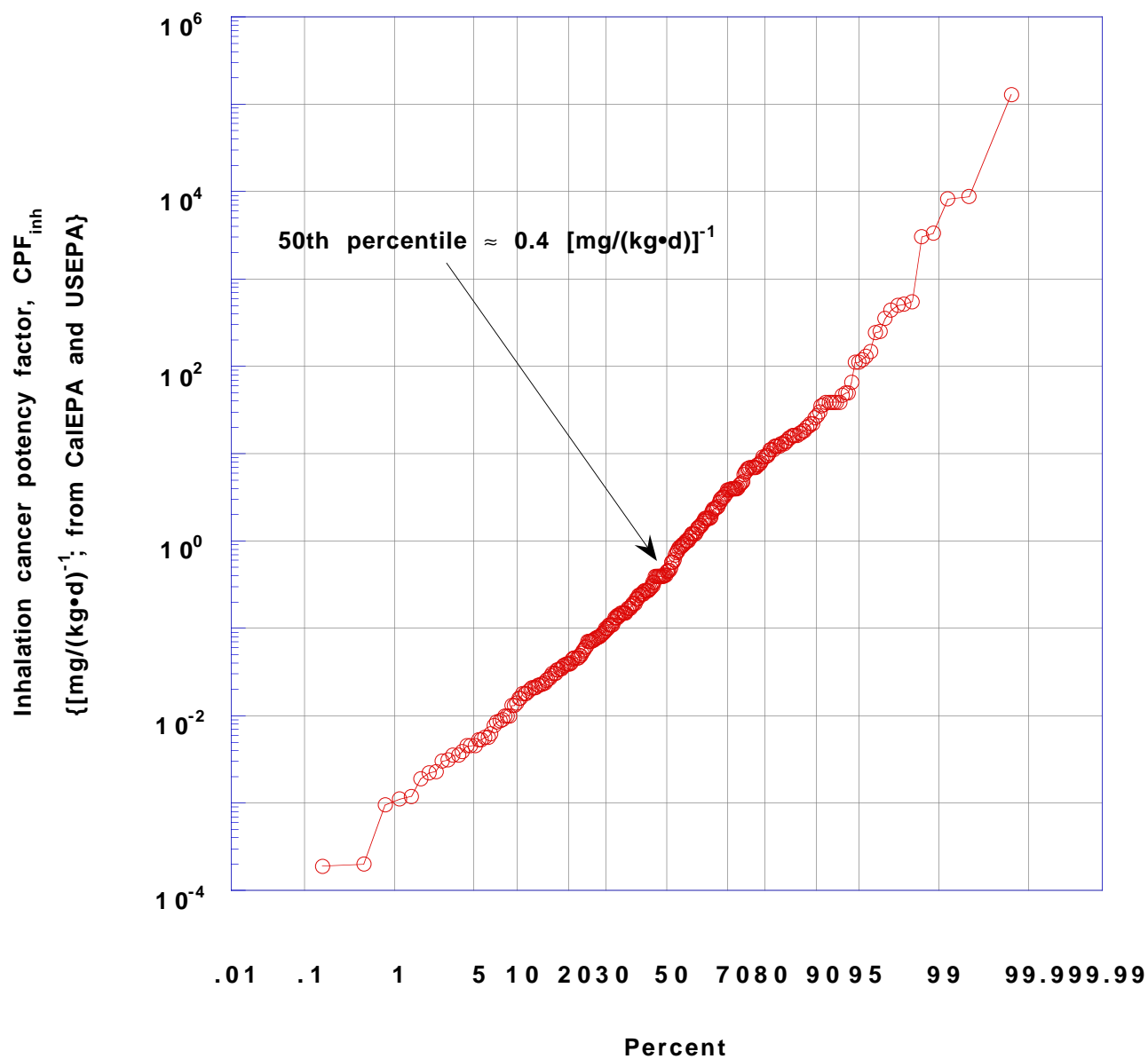
Figure VI-1. Log-probability plot of 300 *inhalation* cancer potency (slope) factors (CPF$_{inh}$s) obtained from regulatory literature (CAL/EPA/OEHHA, 1994b, and EPA, Region IX, 1995) according to procedure described in text and recommended in *PEA Guidance Manual* (CAL/EPA/DTSC, 1994)
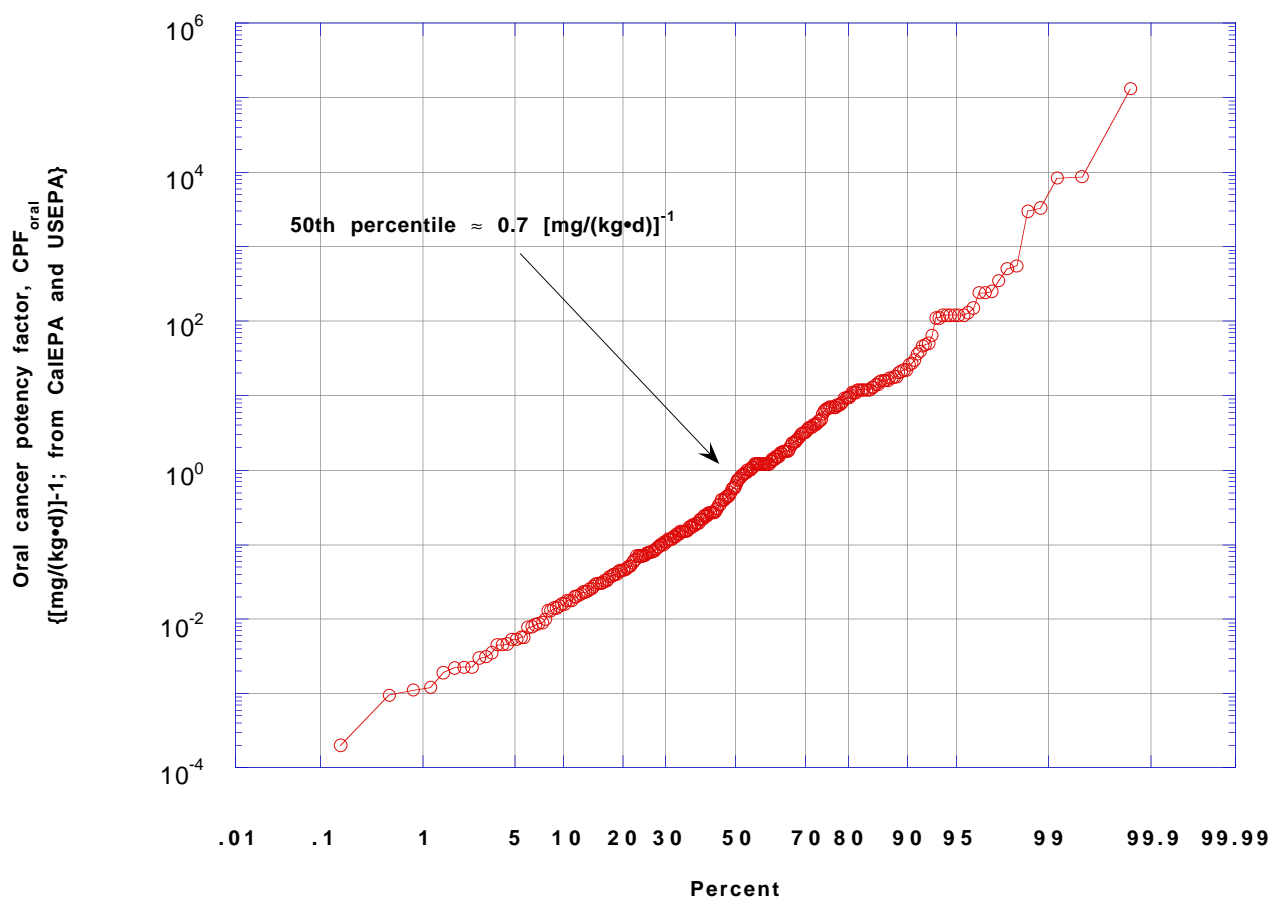
Figure VI-2. Log-probability plot of 306 oral cancer potency (slope) factors (CPF$_{oral}$s) obtained from regulatory literature (CAL/EPA/OEHHA, 1994b and EPA, Region IX, 1995) according to procedure described in text and recommended in *PEA Guidance Manual* (CAL/EPA/DTSC, 1994)
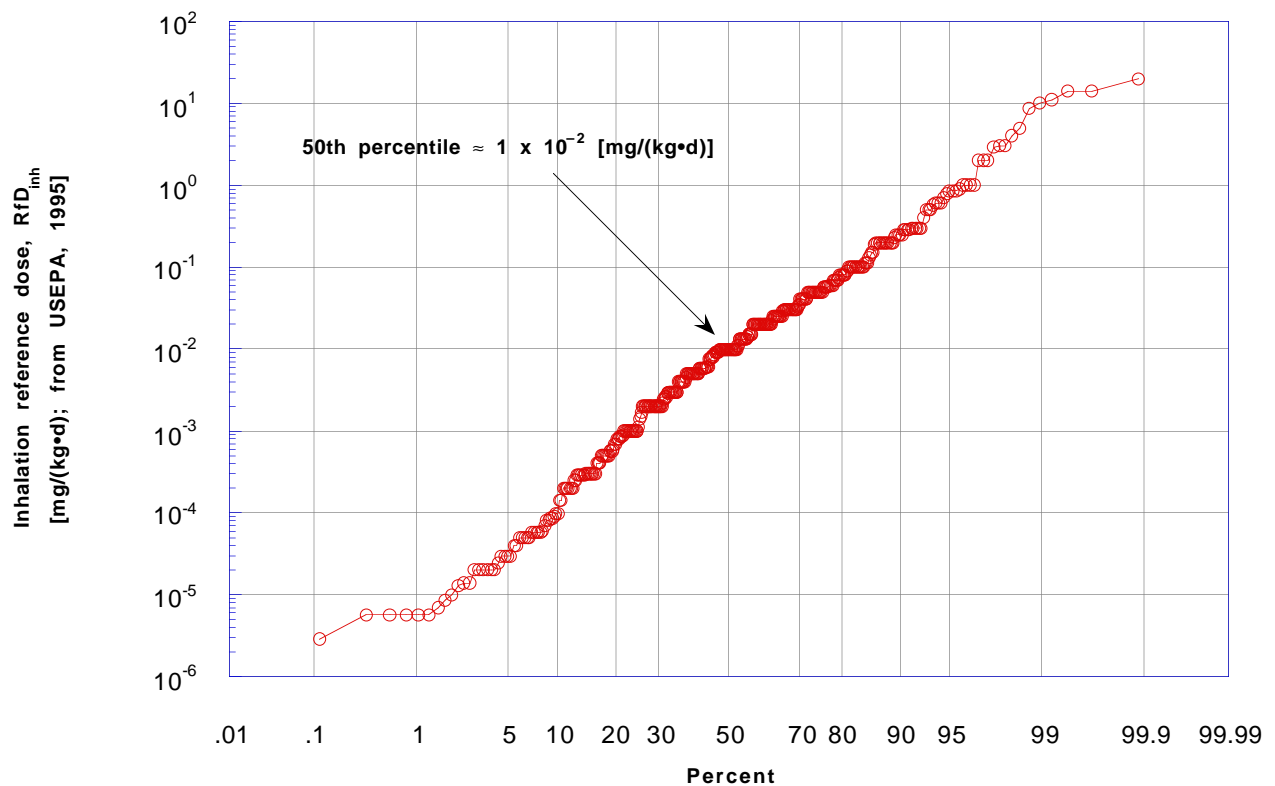
Figure VI-3. Log-probability plot of 479 inhalation reference doses (RfD$_{inh}$s) obtained from PRG regulatory literature (EPA, Region IX, 1995) according to procedure described in text and recommended in *PEA Guidance Manual* (CAL/EPA/DTSC, 1994)
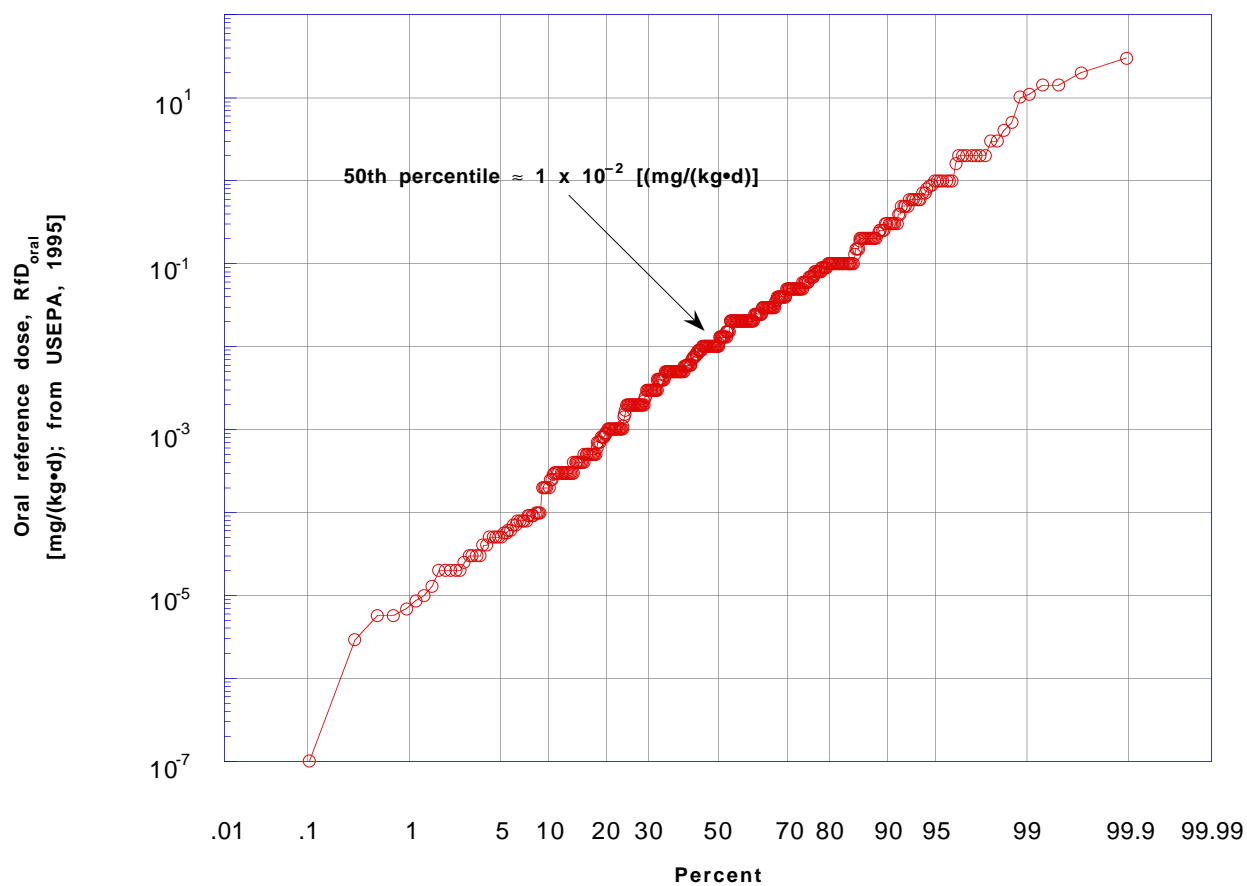
Figure VI-4. Log-probability plot of 479 oral reference doses (RfD$_{oral}$s) obtained from PRG regulatory literature (EPA, Region IX, 1995) according to procedure described in text and recommended in *PEA Guidance Manual* (CAL/EPA/DTSC, 1994)

Table VI-1. List of chemicals included in the designation "VHS"[a]

Chemical name		
Bromodichloromethane	Chloromethane	1,1,2,2-Tetrachloroethane
Bromoform	Dibromochloromethane	Tetrachloroethylene
Bromomethane	1,2-Dichlorobenzene	1,1,1-Trichloroethane
1,2-Dichloroethane	1,3-Dichlorobenzene	1,1,2-Trichloroethane
1,1-Dichloroethylene	1,4-Dichlorobennzene	Trichloroethylene
trans-1,2-Dichloroethylene	Dichlorodifluoromethane	Trichlorofluoromethane
Carbon tetrachloride	1,1-Dichloroethane	Vinyl chloride
Chlorobenzenne	1,2-Dichloropropane	
Chloroethane	cis-1,3-Dichloropropene	
2-Chloroethylvinyl ether	trans-1,3-Dichloropropene	
Chloroform	Methylene chloride	

[a] Grandfield, 1989.

Section VII.

Derivation of Potential Carcinogenic Risk, and Chronic and Acute Noncarcinogenic Hazard for Maximally Exposed Individuals (MEIs)

SECTION VII. DERIVATION OF POTENTIAL CARCINOGENIC RISK, AND CHRONIC AND ACUTE NONCARCINOGENIC HAZARD FOR MAXIMALLY EXPOSED INDIVIDUALS (MEIs)

VII.1 Introduction

The procedures described in this section were used to perform the computations necessary to estimate the total, excess, lifetime cancer risk (R) and the total values for the indices of chronic and acute, noncarcinogenic hazard (i.e., the hazard quotients, Chronic-HQ and Acute-HQ, respectively) for each of the maximally exposed individuals, MEI_ps (where p designates the individual receptor—either an adult on site [aos]; or an adult worker off site [awo]; or an adolescent at a child daycare center [cdc]; or a hypothetical resident [RES_{hyp}]; or a currently existing resident [RES_{real}]) at their respective locations. These arithmetic operations are in agreement with those recommended in *the Preliminary Endangerment Assessment (PEA) Guidance Manual* (California Environmental Protection Agency, Department of Toxic Substances Control [CAL/EPA/DTSC], 1994) for performing such calculations.

VII.2 Carcinogenic Risk

The mathematical expression given in **Equation VII-1** represents the general procedure for determining excess, lifetime cancer risk for a specific receptor type *p* (e.g., aos, awo, cdc, RES_{hyp}, or RES_{real}) as a consequence of exposure to a particular chemical *i* by means of a distinct exposure pathway *r* (e.g., on the basis of pathway screening, exposure occurs predominantly either directly from inhalation [inh] or indirectly from ingestion of contaminated, homegrown produce [oral]) at a specific location *l*, as a result of the use of a treatment unit *q*, contributing to the Decontamination and Waste Treatment Facility (DWTF) source term *F*, which is either the stack at the DWTF (*F* = 1), the area at the DWTF (*F* = 2), the stack at Building 612 (*F* = 3), or the Area 612 Facility (*F* = 4).

$$R_{p,i,l,r,q,F} = S_i \times \left[\frac{\chi}{Q}\right]_{l,F} \times \prod_{p,r}^{risk} \times CPF_{i,r}, \tag{VII-1}$$

where:

$R_{p,i,l,r,q,F}$ = Excess, lifetime cancer risk for an individual, identified as receptor *p*, as a result of exposure to chemical *i*, at a location *l* by exposure route *r* (on the basis of exposure pathway screening, *r* is either direct inhalation [inh] or ingestion of contaminated, homegrown produce [oral]), as a consequence of emission from treatment unit *q*, contributing to source *F*.

S_i = Scaled, annual emission rate (kg/y converted to g/s) for chemical *i* (as described in **Section III**, S_i is the product of the scaled, annual mass of a chemical requiring treatment, and applicable emission and abatement factors that are functions of the treatment process and the physical properties of the chemical);

$[\chi/Q]_{l,F}$ = Normalized, annual-average, ambient air concentration ($\mu g/m^3$ per g/s) at location l, as a result of a DWTF or an Area 612 Facility source F, associated with hazardous waste operations at Lawrence Livermore National Laboratory (LLNL) (see **Section IV** for more details);

$\prod_{p,r}^{risk}$ = Product of the intermedia transfer factor (ITF) and the pathway exposure factor (PEF) for deriving carcinogenic risk, which is applicable to receptor p and exposure route r (as explained in **Section V**, dimensions for this product, Π, are a function of r; for example, if r equates to direct inhalation, then Π_{inh} is expressed in units of $m^3/[kg\bullet d]$; and if r equates to ingestion of contaminants on homegrown produce, then Π_{oral} is expressed in units of $kg/[kg\bullet d]$); and

$CPF_{i,r}$ = Cancer potency (slope) factor $\{Risk/[mg/(kg\bullet d)]\}$ for chemical i and route of exposure r (cancer potency factors [CPFs] are discussed and presented in **Section VI**).

Because **Equation VII-1** is linear and yields the risk to a receptor p at only one location l from only one chemical i by means of only one of the two dominant exposure pathways, r (i.e., direct inhalation [r = inh], and ingestion of contaminated, homegrown produce [r = oral]); the value for χ/Q can be generalized to a unit value of 1.0. This allows operations to be performed independent of location-specific χ/Q values. (**Equation VII-1** is implemented for each source in **Appendix F** for the inhalation pathway and **Appendix F′** for the ingestion pathway.)

The risk for the receptor for a unit-value χ/Q from all chemical emissions related to the individual treatment unit and the source to which it is connected ($R_{p,l,r,q,F}$) is then obtained by applying **Equation VII-2** for each pathway:

$$R_{p,l,r,q,F} = \sum_{i=1}^{n} R_{p,i,l,r,q,F} \,. \tag{VII-2}$$

The treatment unit-related, source-specific contributions to the complete risk for a receptor p for a unit-value χ/Q is $R_{p,l,r,F}$ and is developed by summing risk from all treatment processes q that are connected to a particular source F associated with them by **Equation VII-3**.

$$R_{p,l,r,F} = \sum_{q=1}^{k} R_{p,l,r,q,F} \,. \tag{VII-3}$$

For example, there is only one treatment process for the Building 612 stack, Area 612 Facility, and the DWTF area sources. However, the DWTF stack is the source of emissions from 10 different treatment units (see **Table VII-1**).

The next step is to sum the risks for the receptor p from exposure to the chemical by each of the two dominant exposure pathways, r's, so that the entire risk for this receptor ($R_{p,l,F}$), contributing to a source F and based on a unit-value for χ/Q can be obtained as described by **Equation VII-4:**

$$R_{p,l,F} = \sum_{r=1}^{2} R_{p,l,r,F}.$$ (VII-4)

To estimate the total risk for a receptor p at the coordinates of a real location L, as a consequence of emissions from all four sources (i.e., the DWTF stack, the Building 612 stack, the DWTF, and the Area 612 Facility), $F = 1$ to 4, we multiplied the results from **Equation VII-4** for each of the sources by the location-specific χ/Q, and the resulting four location-specific products are summed by **Equation VII-5**. The result is the term representing the total, lifetime, excess cancer risk for the receptor of interest, $R_{p,L}$:

$$R_{p,L} = \sum_{F=1}^{4} R_{p,L,F}.$$ (VII-5)

The maximum $R_{p,L}$ is then found by searching for it mathematically in a spreadsheet containing all $R_{p,L}$s for all locations. Because the calculations were based on a unit χ/Q, we obtained location-specific calculations by multiplying by the location-specific χ/Q (see **Appendix L**). This maximum $R_{p,L}$ value is associated with the MEI for that particular receptor p with respect to incremental, excess, lifetime cancer risk.

Because the mathematical process for deriving MEI$_p$s involves linear relationships, the need for repeating the calculations by using **Equations VII-1** through **VII-5** for every receptor category and location was truncated significantly by the following procedure: first, **Equations VII-1** through **VII-5** were used to derive an R_{RES} at all locations for which χ/Q values were predicted. Then, the ratios of the PEF for inhalation and for ingestion of homegrown produce, respectively, for other receptors p (e.g., $p = cdc$) as compared to a residential receptor were derived. These ratios are identified as receptor-specific conversion factors for exposure with respect to risk and are shown in **Table VII-2**. Because the ratios are identical for both the inhalation and oral exposure pathways of the respective receptor categories, the ratio can then be applied to the total risk from both exposure pathways determined by using **Equation VII-5**, which was based on residential exposure. These products now represent the $R_{p,L,F}$s for that receptor category of interest and are used in **Equation VII-6** below, where RCF represents the receptor-specific conversion factor stated in **Table VII-2**, to derive the respective $R_{p,L}$ values for all receptor types of interest.

$$R_{p,L} = R_{res} \times RCF_p$$ (VII-6)

The MEI$_p$s (where $p = aos$, awo, cdc, RES$_{real}$, and RES$_{hyp}$) with respect to potential, excess, lifetime cancer risk are summarized in **Table VII-3** for individual sources and all sources combined. Included in **Table VII-3** are the applicable location-specific χ/Q values and receptor-specific conversion factors for exposure with respect to risk. **Figure VII-1** shows the locations of all MEI$_p$s.

According to the results summarized in **Table VII-2**, all MEI$_p$s are shown to have total risks less than 1×10^{-6}. According to the U.S. Environmental Protection Agency (EPA) (1990), the

10^{-6} risk level should be used as the point of departure in establishing an acceptable risk level where appropriate or relevant, and applicable requirements do not exist. For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess, upper-bound, lifetime cancer risk to an individual of between 10^{-4} to 10^{-6}. Therefore, the values for risk appearing in **Table VII-2** are below the levels for which additional risk management would be recommended.

VII.3 Chronic Noncarcinogenic Hazard

A mathematical expression (**Equation VII-7**), similar but not identical to **Equation VII-1**, is used for determining the chronic, noncarcinogenic hazard (i.e., *Chronic-HQ*) for a specific receptor p (e.g., aos, awo, cdc, RES$_{hyp}$, or RES$_{real}$) as a consequence of exposure to a particular chemical i, at a location l by means of a distinct exposure pathway r (e.g., on the basis of pathway screening, exposure occurs predominantly either directly from inhalation [inh], or indirectly from ingestion of contaminated, homegrown produce [oral]), as a result of the use of a treatment unit q, contributing to the source term F, which is either the DWTF stack ($F = 1$), the DWTF area ($F = 2$), the Building 612 stack ($F = 3$), or the Area 612 Facility ($F = 4$).

$$Chronic - HQ_{p,i,l,r,q,F} = \frac{S_i \times \left[\dfrac{\chi}{Q}\right]_{l,F} \times \prod_{p,r}^{hazard}}{RfD_{i,r}}, \qquad \text{(VII-7)}$$

where:

$Chronic\text{-}HQ_{p,i,l,r,q,F}$ = Hazard quotient for an individual, identified as receptor p, as a result of exposure to chemical i, at a location l by exposure route r (on the basis of exposure pathway screening, r is either direct inhalation [inh] or ingestion of contaminated, homegrown produce [oral]), as a consequence of emission from treatment unit q, contributing to source F.

S_i = Scaled, annual emission rate (kg/y converted to g/s) for chemical i (as described in **Section III**, S_i is the product of the scaled, annual mass of a chemical requiring treatment, and applicable emission and abatement factors that are functions of the treatment process and the physical properties of the chemical);

$[\chi/Q]_{l,F}$ = Normalized, annual-average, ambient air concentration (μg/m^3 per g/s) at location l, as a result of a DWTF or an Area 612 Facility source F associated with hazardous waste operations at LLNL (see **Section IV** for more details);

$$\prod_{p,r}^{hazard}$$ = Product of the ITF and the PEF for hazard and applicable to receptor p and exposure route r (as explained in **Section V**, dimensions of the product, Π, are a function of r; for example, if r equates to direct inhalation, then Π_{inh} is expressed in units of m^3/(kg•d); and if r equates to ingestion of contaminants on homegrown produce, then Π_{oral} is expressed in units of kg/[kg•d]);

$RfD_{i,r}$ = Reference dose (RfD) (representing threshold at or below which no observed adverse health effects are expected and expressed in units of mg/[kg•d]) for chemical i, and route of exposure r (RfDs are discussed and presented in **Section VI**).

Equation VII-7 is implemented for each source in **Appendix G** for the inhalation pathway and in **Appendix G′** for the ingestion pathway.

Again, the need for repeating the calculations using **Equation VII-7**, along with modified versions of **Equation VII-2** through **Equation VII-6**, where *Chronic-HQ*s are substituted for *R*s, for every receptor category was truncated significantly. In this case, **Equation VII-7** and the modified versions of **Equations VII-2** through **VII-6** (where *Chronic-HQ*s are substituted for *R*s) were used to derive a *Chronic-HQ$_{RES,L}$* at all precise locations L for which χ/Q values were predicted. As for the risk calculations, the hazard associated with each of the DWTF stack sources were added (see **Table VII-4**). Then, the ratios of the PEF for inhalation and for the ingestion of homegrown produce, respectively, for a receptor p (e.g., $p = cdc$), and for the residential receptor ($p = RES$) were derived. These ratios are identified as receptor-specific conversion factors for exposure with respect to chronic hazard and are shown in **Table VII-5**. Because the ratios are identical for both the inhalation and the oral exposure pathways of the respective receptor categories, the ratio can be applied to the total hazard from both exposure pathways determined by using the modified version of **Equation VII-5** (where the *Chronic-HQ$_{p,L,F}$* is substituted for the $R_{p,L,F}$). These products now represent the *Chronic-HQ$_{p,L,F}$*s for that receptor category of interest and are used in the modified version of **Equation VII-6** to derive the respective *Chronic-HQ$_{p,L}$* values for all receptors of interest. As before, the maximum of these *Chronic-HQ$_{p,L}$* values represents the MEI$_p$ for this particular receptor category with respect to potential chronic hazard.

The MEI$_p$s (where p = *aos, awo, cdc, RES$_{real}$*, and *RES$_{hyp}$*) with respect to potential chronic hazard are summarized in **Table VII-4** for individual sources and all sources combined. Included in **Table VII-6** are the applicable location-specific χ/Q values and receptor-specific conversion factors for exposure with respect to chronic hazard. (See **Figure VII-1** for the locations of the MEI$_p$s.)

The results summarized in **Table VII-6** clearly indicate that all total, chronic-hazard quotients (*Chronic-HQ$_{p,L}$*) representing MEI$_p$s are less than 1.0. Because no total chronic-hazard quotient in **Table VII-6** exceeds 1.0, the exposures are not considered to yield adverse, noncarcinogenic health effects in the MEI receptors. However, none of these total chronic-hazard quotients includes consideration of lead, which is addressed separately by a physiologically based model.

This model and the results of its application with regard to lead are described in the next part of this section.

VII.3.1 *Noncarcinogenic Hazard from Lead Exposures*

As recommended in the *PEA Guidance Manual* (CAL/EPA/DTSC, 1994), a physiologically based, analytical model called LEADSPREAD, which is written for use with spreadsheet software for a personal computer and obtained electronically with documentation (Carlisle, 1996) from DTSC, was used to evaluate the chronic hazard from exposure to lead released to the atmosphere. As stated in the "Principles" section of the documentation (Carlisle,1996) accompanying the model, the blood-lead concentrations of concern in children and adults are those exceeding 10 μg/dL. Consequently, model output includes results that indicate the 99th-percentile concentration of lead in whole blood. This means that the risk of exceeding the 99th-percentile value, based on the default parameters appearing in LEADSPREAD and adopted for this Health Risk Assessment, is only 1%, for a predicted air concentration.

The LEADSPREAD model was applied to the maximum, predicted atmospheric concentration of lead (3.07×10^{-7} μg/m^3). This maximum concentration was found by: 1) multiplying the product of the scaled, annual emission rate for lead (presented in **Volume 2, "Table 1"** for each unit) from each unit and source by the annual-average χ/Q values for each location for which such a χ/Q value was predicted; 2) summing these results for each location to obtain a location-specific, atmospheric concentration for lead; and finally 3) searching for that location with the highest, maximum air concentration predicted for lead (see **Appendix M**.) This maximum concentration was predicted at the same location as that for the MEI$_{REShyp}$. This result is not unexpected because most of the emissions from DWTF operations originate from the DWTF stack, which is in relatively close proximity (see **Figure VII-1**).

According to the results appearing in **Table VII-7**, the 99th-percentile, blood-lead levels for the adult, child, pica child, and adult in an industrial setting are all well below the 10-μg/dL point of departure for instituting requirements for risk management. Additionally, the concentrations of lead (predicted at all other locations) are all lower than this maximum, so that they too would produce blood-lead levels for all receptors of interest that are well below the 10-μg/dL level at the 99th-percentile. Consequently, these ambient air concentrations also are not anticipated to produce any adverse health effects in any of the exposed receptors.

VII.4 Acute Noncarcinogenic Hazard

The estimated, maximum, 1-hour concentrations at potential receptor locations (expressed in units of micrograms per cubic meter [μg/m^3]) for each of the chemicals of concern that are of specific interest to the state of California Air Toxics "Hot Spots" Program (California Air Pollution Control Officers Association [CAPCOA], 1993; CAL/EPA/Office of Environmental Health Hazard Assessment [OEHHA], 1994 and 1995) are determined for the DWTF and the Area 612 Facility sources separately. Spatial differences between the DWTF and the Area 612 Facility sources are considered sufficient to eliminate from further consideration any significant contribution that the DWTF might make to Area 612 Facility's maximum, 1-hour concentrations at a receptor location, and vice versa.

Maximum, 1-hour concentrations attributable to the DWTF stack and area sources or to the Building 612 stack and the Area 612 Facility sources are determined for each chemical of interest to the state of California Air Toxics "Hot Spots" Program by multiplying the scaled, maximum, 1-hour emission rate (e.g., in units of g/h) reported in **Appendix I** for each chemical emission from a specific treatment process by a location-specific, 1-hour, maximum χ/Q value (described in **Section IV**). Then, the chemical-specific concentrations that result are summed for the DWTF sources and for the Area 612 Facility sources, separately, to arrive at an estimate of the total, ambient air concentration for each chemical of interest at each receptor location that is attributable to either the DWTF or the Area 612 Facility operations. The maximum concentration and its corresponding location for each chemical are then found for DWTF sources and for Area 612 Facility sources.

We evaluated the potential for acute, noncancer health effects for receptors off site from LLNL according to the procedure prescribed by the state of California Air Toxics "Hot Spots" Program (CAPCOA, 1993; CAL/EPA/OEHHA, 1994 and 1995). Specifically, we first compared the predicted, maximum, 1-hour concentration for a chemical of concern to the acute, reference exposure level (*REL*) for that particular chemical for a particular target organ and recorded that quotient. The acute *REL* (generally based on the most sensitive, adverse health effect reported in medical and toxicological literature) is published and defined by the state of California to be the 1-hour concentration ($\mu g/m^3$) at or below which no adverse health effects are anticipated (CAPCOA, 1993; CAL/EPA/OEHHA, 1994). Dividing the maximum, 1-hour concentration by the acute *REL* published by the state of California yields a chemical-specific and target-organ-specific acute-hazard quotient (i.e., Acute-HQ). A value of less than 1.0 for this ratio indicates that the emission and the corresponding, 1-hour, maximum concentration for the emission of a specific chemical are not expected to result in any acute, adverse health effects for the MEI at the exposure point. Furthermore, target-organ-specific hazard quotients were totaled for DWTF chemicals of interest, and separately for Area 612 Facility chemicals of interest. If any of these values exceed 1.0, then there would be a possibility that a combination of maximum, 1-hour concentrations from different chemicals could produce adverse health effects by effecting the same target organ or system. Even though it is extremely unlikely that all chemicals would have maximum emissions during any 1-hour period, the results of this analysis (see **Table VII-8** for the Building 612 stack and the Area 612 Facility sources, and **Table VII-9** for the DWTF stack and area sources) reveal none of these summed Acute-HQ for specific target organs equals a value of 1.0 or greater. This outcome indicates that it is unlikely any individual off site would experience any acute, adverse health effects from short-term exposure to peak 1-hour emissions (separately or in combination) from the DWTF or the Area 612 Facility operations.

As was mentioned, only off-site, ambient air concentrations were examined for potential acute hazard. This is because the Air Toxics "Hot Spots" Program is not intended to be applicable to occupational exposures to workers. Nevertheless, LLNL policy requires operational controls (i.e., engineering controls, administrative controls, and the use of personal protective equipment) to be established to reduce or eliminate worker exposure above published standards and guidelines, pursuant to U.S. Department of Energy (DOE) Order 5480.10 (DOE, 1985). Examples of such operational controls are described in the Facility Safety Plans for the existing waste treatment operations at Area 514 and Area 612 (LLNL, 1989; LLNL, 1992). For these

reasons, and especially because protection of worker health and safety are a priority, adults on site (i.e., $p = aos$) are unlikely to be at risk or subject to acute hazard.

VII.5 References

California Air Pollution Control Officers Association (CAPCOA). 1993. *Air Toxics "Hot Spots" Program, Revised 1992 Risk Assessment Guidelines*, Toxics Committee of the California Air Pollution Control Officers Association, in consultation with the Air Toxicology Unit, Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment, and the Special Projects Section, Toxic Air Contaminant Identification Branch, Air Resources Board. Sacramento. CA, October.

California Environmental Protection Agency, Department of Toxic Substances Control (CAL/EPA/DTSC). 1994. *Preliminary Endangerment Assessment (PEA) Guidance Manual (A guidance manual for evaluating hazardous substances release sites)*. California Environmental Protection Agency, Department of Toxic Substances Control, Sacramento, CA, January

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1994. *Air Toxics "Hot Spots "Program Risk Assessment Guidelines: Part 1, Evaluation of Acute Non-Cancer Health Effects, Draft for Public Comment.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA, December.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1995. *Technical Support Document for The Determination of Acute Toxicity Exposure Levels for Airborne Toxicants, Draft for Public Comment.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA, January.

Carlisle, J. 1996, "Chapter 7. Assessment of Health Risks from Inorganic Lead in Soil," in *Supplemental Guidance for Human health Multimedia Risk Assessment Hazardous Waste Sites and Permitted Facilities,* Office of the Science Advisor, Department of Toxic Substances Control, State of California Environmental Protection Agency, Sacramento, CA, August (documentation for the spreadsheet model LEADSPREAD, obtained electronically from CALEPA using world wide web address).

Lawrence Livermore National Laboratory (LLNL). 1989. *Facility Safety Procedures, Radioactive and Hazardous Waste Treatment Facility: Building 514 Complex*. Lawrence Livermore National Laboratory, Livermore, CA, Procedure 514, December 5.

Lawrence Livermore National Laboratory (LLNL). 1992. *Facility Safety Procedures, Radioactive and Hazardous Waste Treatment and Storage Facilities: The 612 Complex and Building 693*. Lawrence Livermore National Laboratory, Livermore, CA, April, FSP-612.

U.S. Environmental Protection Agency (EPA). 1990. *National Oil and Hazardous Substances Pollution Contingency Plan. Final Rule.* U.S. Environmental Protection Agency, Washington, D.C. (40CFR300), *Federal Register.* **55**(46), 8666-8865.

U.S. Department of Energy (DOE). 1985. *Contractor Industrial Hygiene Program.* U.S. Department of Energy, Washington, D.C., June 26, DOE Order 5480.10.

VII.6 Acronyms

aos	Adult on site
awo	Adult worker off site
CAL/EPA	California Environmental Protection Agency
CAPCOA	California Air Pollution Control Officers Association
cdc	child daycare center
CPF	Cancer potency factor
DOE	U.S. Department of Energy
DTSC	Department of Toxic Substances Control
DWTF	Decontamination and Waste Treatment Facility
EPA	U.S. Environmental Protection Agency
HQ	Hazard quotient
ITF	Intermedia-transfer factor
LLNL	Lawrence Livermore National Laboratory
MEI	Maximally exposed individual
OEHHA	Office of Environmental Health Hazard
PEA	Preliminary Endangerment Assessment
PEF	Pathway exposure factor
REL	Recommended Exposure Limit
RES_{real}	Residence real
RES_{hyp}	Residence hypothetical
RFD	Reference dose
UTM	Universal Transverse Mercator
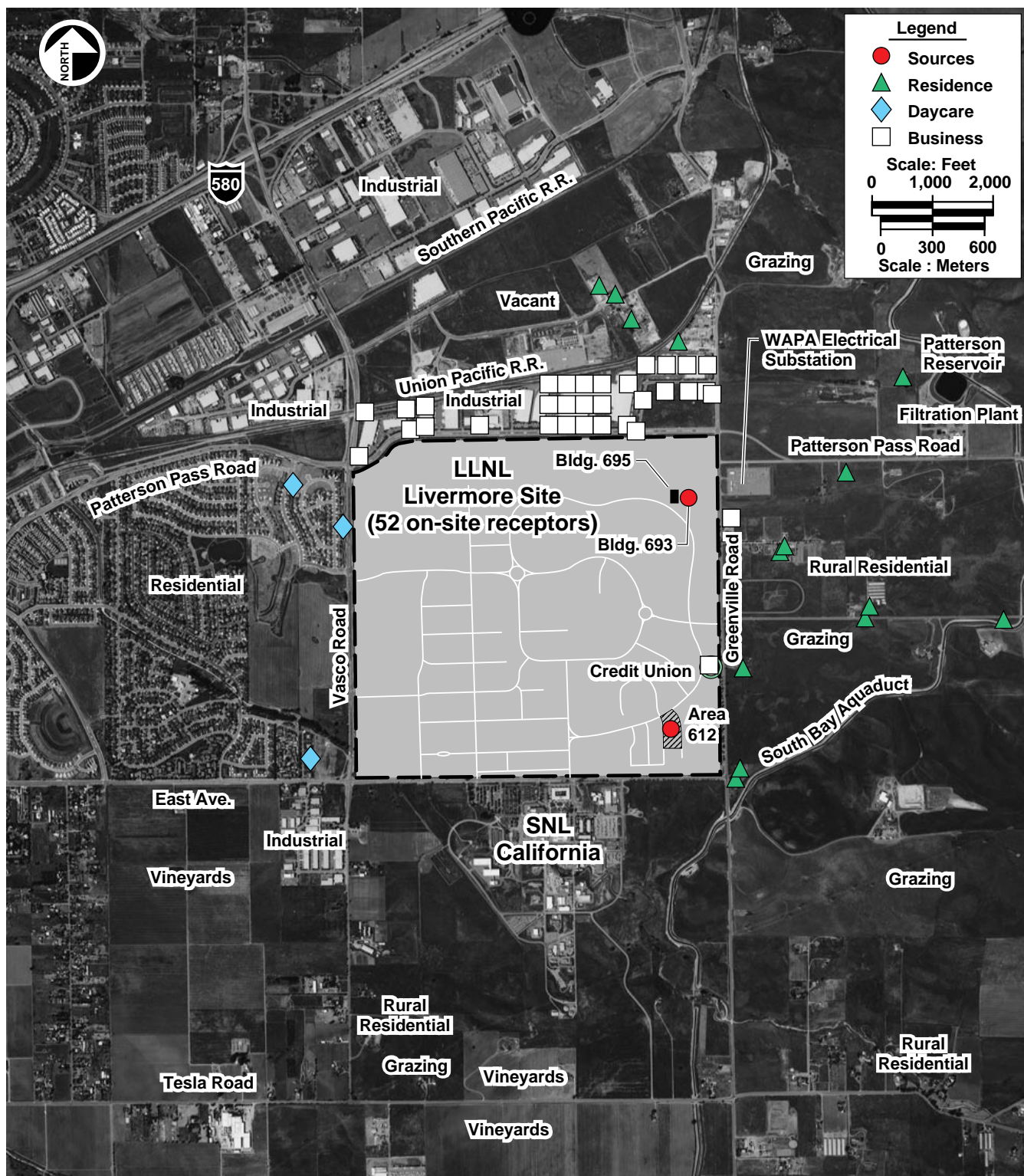
Figure VII-1. LLNL and Surrounding Area with Location of MEI$_{ps}$

Table VII-1. Summary of total risk based on a unit χ/Q value for each waste treatment facility or unique emission source

Waste treatment facility	Waste treatment unit	Lifetime excess carcinogenic risk for the inhalation pathway based on a unit χ/Q	Lifetime excess carcinogenic risk for the ingestion pathway based on a unit χ/Q	Total lifetime excess carcinogenic risk based on a unit χ/Q
DWTF	Tank Farm	1.84E-09	N/A	1.84E-09
	Centrifuge Unit	8.56E-08	N/A	8.56E-08
	Filtration Unit	9.76E-09	N/A	9.76E-09
	Solidification Unit	1.57E-07	3.22E-12	1.57E-07
	Shredder/Chopper Unit	3.53E-09	8.53E-12	3.53E-09
	Debris Washer Unit	1.25E-10	5.22E-12	1.30E-10
	Uranium Bleaching Unit	3.76E-10	N/A	3.76E-10
	Amalgamation Reactor	1.40E-15	N/A	1.40E-15
	Pressure Reactor	9.07E-10	2.61E-11	9.33E-10
	Water Reactor	4.31E-09	4.59E-14	4.31E-09
Sum of Risks	**DWTF total, lifetime excess carcinogenic risk based on a unit χ/Q**	2.64E-07	4.31E-11	2.64E-07
DWTF area source represented by blending/ transfer operations	**DWTF area source total, lifetime excess carcinogenic risk based on a unit χ/Q**	1.64E-10	N/A	1.64E-10
Building 612 stack from decontamination booth	**Building 612 stack total, lifetime excess carcinogenic risk based on a unit χ/Q**	4.81E-09	1.01E-11	4.82E-09
Area 612 Facility source represented by blending/ transfer operations	**Area 612 Facility total, lifetime excess carcinogenic risk based on a unit χ/Q**	1.64E-10	N/A	1.64E-10

Table VII-2. Receptor-specific conversion factors by which $R_{RESreal,L,F}$ can be multiplied to derive the corresponding $R_{p,L,F}$ of interest

Receptor-specific conversion factor for exposure with respect to risk	Inhalation ratio	Oral ratio
res/RES	1.00	1.00
aos/RES	1.57E-1	1.57E-1
awo/RES	1.57E-1	1.57E-1
cdc/RES	8.74E-2	8.74E-2

Table VII-3. Estimated lifetime excess carcinogenic risk for Maximally Exposed Individuals (MEIs)

Type of MEI	Location of MEI (UTM)	Waste treatment facility or unique source	Lifetime excess carcinogenic risk based on a unit χ/Q	Location-specific χ/Q value ($\mu s/m^3$)	Receptor-specific conversion factor for exposure	Source-specific lifetime excess carcinogenic risk
$MEI_{RESreal}$	15531, 72429	DWTF stack	2.64E-07	1.73E+00	1.00E+00	4.57E-07
		DWTF area	1.64E-10	4.88E+00	1.00E+00	7.98E-10
		Building 612 stack	4.82E-09	2.04E+00	1.00E+00	9.84E-09
		Area 612 Facility	1.64E-10	3.10E+00	1.00E+00	5.07E-10
MEI location-specific, total, lifetime, excess carcinogenic risk contributed by all sources						4.68E-07
MEI_{REShyp}	15250, 72500	DWTF stack	2.64E-07	2.70E+00	1.00E+00	7.13E-07
		DWTF area	1.64E-10	1.46E+01	1.00E+00	2.39E-09
		Building 612 stack	4.82E-09	1.45E+00	1.00E+00	6.99E-09
		Area 612 Facility	1.64E-10	3.03E+00	1.00E+00	4.95E-10
MEI location-specific, total, lifetime, excess carcinogenic risk contributed by all sources						7.22E-07
MEI_{cdc}	13007, 71051	DWTF stack	2.64E-07	1.72E-01	8.74E-02	3.97E-09
		DWTF area	1.64E-10	9.68E-01	8.74E-02	1.38E-11
		Building 612 stack	4.82E-09	2.76E-01	8.74E-02	1.16E-10
		Area 612 Facility	1.64E-10	1.64E+00	8.74E-02	2.34E-11
MEI location-specific, total, lifetime, excess carcinogenic risk contributed by all sources						4.12E-09
MEI_{awo}	16986, 72712	DWTF stack	2.64E-07	7.07E-01	1.57E-01	2.93E-08
		DWTF area	1.64E-10	8.13E-01	1.57E-01	2.09E-11
		Building 612 stack	4.82E-09	1.05E+00	1.57E-01	7.95E-10
		Area 612 Facility	1.64E-10	7.79E-01	1.57E-01	2.00E-11
MEI location-specific, total, lifetime, excess carcinogenic risk contributed by all sources						3.01E-08
MEI_{aos}	14500, 72000	DWTF stack	2.64E-07	7.38E-01	1.57E-01	3.06E-08
		DWTF area	1.64E-10	1.07E+00	1.57E-01	2.75E-11
		Building 612 stack	4.82E-09	2.73E-01	1.57E-01	2.07E-10
		Area 612 Facility	1.64E-10	3.43E+00	1.57E-01	8.81E-11
MEI location-specific, total, lifetime, excess carcinogenic risk contributed by all sources						3.09E-08

**Table VII-4. Summary of total noncarcinogenic hazard indices based on a unit
χ/Q for each waste treatment facility or unique emission source**

Waste treatment facility or unique source	Waste treatment unit	Hazard index for the inhalation pathway based on a unit χ/Q	Hazard index for the ingestion pathway based on a unit χ/Q	Total hazard index based on a unit χ/Q
DWTF	Tank Farm	5.07E-05	N/A	5.07E-05
	Centrifuge Unit	2.55E-03	N/A	2.55E-03
	Filtration Unit	7.44E-04	N/A	7.44E-04
	Solidification Unit	1.74E-03	8.51E-09	1.74E-03
	Shredder/Chopper Unit	1.71E-04	2.93E-09	1.71E-04
	Debris Washer Unit	5.60E-06	1.21E-09	5.60E-06
	Uranium Bleaching Unit	2.96E-05	N/A	2.96E-05
	Amalgamation Reactor	2.55E-04	N/A	2.55E-04
	Pressure Reactor	7.81E-04	3.31E-09	7.81E-04
	Water Reactor	1.46E-03	1.82E-10	1.46E-03
Sum of risks	**DWTF hazard index based on a unit χ/Q**	7.79E-03	1.61E-08	7.79E-03
DWTF area source represented by blending/ transfer operations	**DWTF area source hazard index based on a unit χ/Q**	6.27E-06	N/A	6.27E-06
Building 612 stack from decontamination booth	**Building 612 stack hazard index based on a unit χ/Q**	2.13E-04	5.56E-08	2.13E-04
Area 612 Facility source represented by blending/ transfer operations	**Area 612 Facility hazard index based on a unit χ/Q**	6.27E-06	N/A	6.27E-06

Table VII-5. Receptor-specific conversion factors by which Chronic-HQ$_{RESreal,L,F}$ can be multiplied to derive the corresponding Chronic-HQ$_{p,L,F}$ of interest

Receptor-specific conversion factor for exposure with respect to chronic hazard	Inhalation ratio	Oral ratio
res/RES	1.00	1.00
aos/RES	7.14E-2	7.14E-2
awo/RES	7.14E-2	7.14E-2
cdc/RES	1.66E-1	1.66E-1

Table VII-6. Estimated noncarcinogenic hazard indices for Maximally Exposed Individuals (MEIs)

Type of MEI	Location of MEI (UTM)	Waste treatment facility or unique source	Hazard index based on a unit χ/Q	Location-specific χ/Q value ($\mu s/m^3$)	Receptor-specific conversion factor for exposure	Source-specific hazard index
$MEI_{RESreal}$	15531, 72429	DWTF stack	7.79E-03	1.73E+00	1.00E+00	1.35E-02
		DWTF area	6.27E-06	4.88E+00	1.00E+00	3.06E-05
		Building 612 stack	2.13E-04	2.04E+00	1.00E+00	4.34E-04
		Area 612 Facility	6.27E-06	3.10E+00	1.00E+00	1.94E-05
MEI location-specific, total hazard index contributed by all sources						1.40E-02
MEI_{REShyp}	15250, 72500	DWTF stack	7.79E-03	2.70E+00	1.00E+00	2.10E-02
		DWTF area	6.27E-06	1.46E+01	1.00E+00	9.16E-05
		Building 612 stack	2.13E-04	1.45E+00	1.00E+00	3.09E-04
		Area 612 Facility	6.27E-06	3.03E+00	1.00E+00	1.90E-05
MEI location-specific, total hazard index contributed by all sources						2.15E-02
MEI_{cdc}	13007, 71051	DWTF stack	7.79E-03	1.72E-01	1.66E-01	2.22E-04
		DWTF area	6.27E-06	9.68E-01	1.66E-01	1.01E-06
		Building 612 stack	2.13E-04	2.76E-01	1.66E-01	9.75E-06
		Area 612 Facility	6.27E-06	1.64E+00	1.66E-01	1.71E-06
MEI location-specific, total hazard index contributed by all sources						2.35E-04
MEI_{awo}	16986, 72712	DWTF stack	7.79E-03	7.07E-01	7.14E-02	3.93E-04
		DWTF area	6.27E-06	8.13E-01	7.14E-02	3.64E-07
		Building 612 stack	2.13E-04	1.05E+00	7.14E-02	1.60E-05
		Area 612 Facility	6.27E-06	7.79E-01	7.14E-02	3.49E-07
MEI location-specific total hazard index contributed by all sources						4.10E-04
MEI_{aos}	14750, 71250	DWTF stack	7.79E-03	2.76E-01	7.14E-02	1.54E-04
		DWTF area	6.27E-06	1.26E+00	7.14E-02	5.64E-07
		Building 612 stack	2.13E-04	5.86E-01	7.14E-02	8.90E-06
		Area 612 Facility	6.27E-06	6.83E+02	7.14E-02	3.06E-04
MEI location-specific total hazard index contributed by all sources						4.69E-04

Table VII-7. Chronic noncarcinogenic hazard from lead for the Maximally Exposed Individual (atmospheric lead concentration estimated to be 3.0×10^{-7} μg/m^3)[a]

Exposed receptor individual	99th-percentile blood-lead level (μg/dL)
Adult	1.9
Child	4.4
Pica child	4.4
Adult in industrial setting	2.0

[a]   Based on application of LEADSPREAD and accompanying documentation (Carlisle, 1996).

Table VII-8. Acute-Hazard Quotients based on reference exposure levels (RELs) for Building 612 stack and Area 612 Facility sources

Target organ or system	Maximum χ/Q 1-h acute REL hazard quotient[a] for Area 612 source	Maximum χ/Q 1-h acute REL hazard quotient[a] for Building 612 stack source	Total target-organ-specific HQ for Building 612 stack and Area 612 Facility
Central nervous system	1.03E-2	3.60E-2	4.63E–2
Eye	3.49E–5	1.32E-1	1.32E-1
Gastrointestinal, kidney, and liver	1.81E-10	1.51E-2	1.51E-2
Immune system and blood	1.48E-4	2.10E-2	2.12E-2
Reproductive/developmental	5.21E-2	9.04E-2	1.42E-1
Respiratory	5.24 E–2	5.26E-1	5.78E-1
Skin		1.83E-8	1.83E-8

[a]   Concentration in breathing zone/REL.

Table VII-9. Acute-Hazard Quotients based on reference exposure levels (RELs) for DWTF stack and area sources

Target organ or system	Maximum χ/Q 1-h acute REL hazard quotient[a] for DWTF area source	Maximum χ/Q 1-h acute REL hazard quotient[a] for DWTF stack source	Total target-organ-specific HQ for DWTF area and stack
Central nervous system	2.67E-2	9.90E-2	1.26E-1
Eye	9.06E-5	1.45E-1	1.45E-1
Gastrointestinal, kidney, and liver	4.68E-10	2.91E-2	2.91E-2
Immune system and blood	3.85E-4	1.29E-2	1.33E-2
Reproductive/developmental	1.35E-1	3.36E-2	1.69E-1
Respiratory	1.36E-1	5.87E-1	7.23E-1
Skin		1.09E-9	1.09E-9

[a] Concentration in breathing zone/REL.

Section VIII.

Radiological Dose and Risk

SECTION VIII. RADIOLOGICAL DOSE AND RISK

VIII.1   Introduction

Emissions of radionuclides to air by U.S. Department of Energy (DOE) facilities are regulated by the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) (40 Code of Federal Regulations [CFR] Part 61, Subpart H) of the Clean Air Act, and by DOE Orders 5400.1, *General Environmental Protection Program*, and 5400.5, *Radiation Protection of the Public and the Environment*. The NESHAPs regulations limit the emission of radionuclides to the ambient air to activity levels resulting in an annual effective dose equivalent (EDE) not to exceed 100 μSv (10 mrem) to any member of the public. The standards presented in the DOE Orders are for emissions to all environmental media, not just air, and are based on recommendations by the International Commission on Radiological Protection (ICRP, 1977 and 1980). The DOE radiation standards were established independently from and differ from the NESHAPs standards; the DOE standards for protection of the public are 1000 μSv/y (100 mrem/y) EDE for prolonged exposure, and 5000 μSv/y (500 mrem/y) EDE for occasional exposure. (See **Suplement C** for a short discussion of natural and manmade radiation.)

Compliance with NESHAPs regulations are evaluated annually at Lawrence Livermore National Laboratory (LLNL) for existing point and area sources of radionuclides on the site. For most of the Decontamination and Waste Treatment Facility (DWTF) treatment units and the Building 612 Size Reduction Booth, NESHAPs evaluations have not been done because either the units do not yet exist, or they are not currently in operation. For these units, we performed an evaluation similar to NESHAPs, using the emission rates estimated in **Section III** of this health risk assessment. For operations for which NESHAPs evaluations have been done, including the transfer operations that currently occur at Area 612 and are assumed to potentially occur at the DWTF, and the Tank Farm and associated unit operations, previous NESHAPs compliance documentation (Surano *et al.*, 1995) was used to estimate doses.

A brief description of the methodology by which doses were calculated is provided in the next section (**Section VIII.2**), along with estimated doses. Radiological risk, expressed in terms of excess cancer mortalities, was calculated from the estimated radiological doses and is discussed in **Section VIII.3**.

VIII.2   Radiological Dose

For NESHAPs evaluations, radiological dose is calculated using the U.S. Environmental Protection Agency-(EPA) approved CAP88-PC air dispersion and dose assessment computer code (EPA, 1988). The air dispersion model implemented by the CAP88-PC code is a modified, Gaussian plume equation, which estimates average dispersion of radionuclide releases from either continuous point sources or continuous uniform area sources. Plume rise can be calculated for either a momentum-driven or a buoyancy-driven plume. Assessments are done for a polar grid of distances and directions for a radius of 80 km (50 mi) around the source.

The CAP88-PC code computes radionuclide concentrations in air, rates of deposition on ground surfaces, and resultant concentrations in produce, meat, and milk. Estimates of radionuclide concentrations in produce, meat, and milk are made by coupling the output of the atmospheric transport model with terrestrial food chain models within the code.

Annual EDEs (expressed in μSv/y) are estimated in the CAP88-PC code by combining the inhalation rates, ingestion intake rates, air concentrations, and ground surface concentrations with dose conversion factors used in the code. These dose conversion factors account for doses from radioactive decay of ingested or inhaled radionuclides, and from decay of radioactive progeny of the ingested radionuclides that are produced when the radionuclides reside in the body. For ingested or inhaled radionuclides, these dose conversion factors consider the dose the body is committed to for 50 years following intake.

Input to this model includes annual, radionuclide-specific emission rates for either point or area sources; source parameters, such as stack height and plume rise; meteorological data; and agricultural data which specify fractions of produce, meat, and milk that are locally derived. Output from this model is the calculated, annual, radiological EDE for each emission source specified.

Emission data from previous NESHAPs evaluations of the existing Tank Farm and the Area 612 waste transfer operations were utilized in this assessment. Only emissions of H-3 and C-14 from the Tank Farms and transfer operations are considered in this health risk assessment. Emissions of other radionuclides from these units were not considered because waste records suggest that these other radionuclides are likely to be nonvolatile, and emissions of nonvolatile radionuclides from liquid wastes are considered negligible in this assessment (**Section III.2.1.4**). The 1994 NESHAPs evaluation (Surano *et al.*, 1995) provides estimated releases of these radionuclides as follows:

- Tank Farm emissions of 1.3E-04 Ci/y for H-3 and 5.3E-07 Ci/y for C-14

- Area 612 emissions of 1.2 Ci/y for H-3.

For the tank farm, a scaling factor of 6.5 (**Table III-2**) was applied, resulting in an estimated annual emission of 8.5E-04 Ci/y for H-3 and an estimated annual emission of 3.4E-06 Ci/y for C-14. The scaling factor for the Area 612 transfer operations is 2 (**Table III-2**), giving an estimated annual emission of 2.4 Ci/y for H-3 for these operations. Because some of the transfer operations may occur at the DWTF, the same annual emission (2.4 Ci/y) at the DWTF was assumed. This allows the analysis to cover the possibility that all transfers may occur at either location.

For all other treatment units, the scaled and abated emission rates given in **Appendix E** in **Volume 2** were used to evaluate radiological doses. Terrestrial transport parameters and dose conversion factors are not provided in the CAP88-PC code for some radionuclides. Therefore, surrogate radionuclides were selected to represent these radionuclides lacking necessary characterization by CAP88-PC. For example, Rh-102 is a radionuclide that appears as a radionuclide destined for the DWTF, but it does not have the necessary data in the CAP88-PC

code. Therefore, Co-60 was chosen as a surrogate for this radionuclide, based on its similar half-life and similar dosimetric properties. According to the National Council on Radiation Protection's (NCRP) Publication 123 (1996), Co-60 will deliver a similar EDE as Rh-102, per unit concentration of each radionuclide in air. Surrogates were selected on the basis of information in NCRP Publication 123 and are listed in **Table VIII-1**.

Source parameters (i.e., stack heights, plume rise, etc.) used in the CAP88-PC code simulations were specified according to the values presented in **Section IV** of this assessment. Two stacks were considered: the stack at the DWTF, and the stack associated with the Building 612 Size Reduction Unit. Two area sources were also considered: the area source associated with Area 612 waste transfer activities, and the area source associated with proposed DWTF waste transfer activities.

Meteorological data used in the CAP88-PC simulations of radionuclide transport and dose are specific to the LLNL site and are the most recent (for the year 1995) available at the time of the calculations. Agricultural data, which specify the fractional consumption of home-grown produce, meat, and milk, were assumed to be identical to that specified for calculation of doses from nonradiological constituents (**Section V**). Thus, it is assumed that 36% of all produce consumed is home-grown (and, thus, is potentially contaminated with radionuclides deposited from the air), and that meat and milk are not derived from local dairy or beef cattle.

The CAP88-PC simulations were conducted for each treatment unit and handling operation. Doses calculated are specific to the unit or operation and are reported in **Table VIII-2**, along with the major radionuclide contributing to the dose. Doses reported in this assessment are for the location of maximum EDE off site and assume 24-hour-per-day exposures for 365 days per year. For both stacks, these points are beyond the fenceline, but not at coincident locations. For the area sources, the points of maximum, off-site EDE are at the fenceline of the LLNL, but again, not at coincident locations. Furthermore, plumes from the DWTF and Area 612 operations do not significantly overlap; thus, doses from each of these two general areas are not additive. However, doses from units that exhaust to the DWTF stack are additive, as shown in **Table VIII-2**. Although plumes from the DWTF stack and the DWTF area source do not completely coincide, maximum EDEs associated with these two sources were added in this assessment to account for any plume overlap. Similarly, maximum EDEs associated with the Building 612 stack and the Area 612 area source were added, despite the fact that the associated plumes do not completely coincide.

The combined, annual, maximum off-site EDE estimated for the DWTF stack and area source is 4.3E-01 μSv/y. The combined, annual, maximum off-site EDE estimated for the Area 612 area source and Size Reduction Unit stack is 4.1E-02 μSv/y. With the exception of the Debris Washer and the Water Reactor, the major radionuclide contributing to the EDE is H-3, which can be expected due to the frequency of occurrence of H-3 in the waste streams, and the fact that H-3 is not readily abated. For the Debris Washer, the major radionuclide contributing to the EDE is C-14; for this unit only, the emission factor of C-14 was assumed to be 1.0. Process considerations for the Debris Washer suggested the potential for 100% release of C-14 (**Section III.2.1.4**). For the Water Reactor, only U-238 and D38 (depleted uranium) were listed for waste streams characterized for this unit. Risks associated with these doses are discussed in the next section.

VIII.3   Radiological Risk

To estimate the lifetime excess cancer mortality risk associated with maximum exposure to radionuclides at the locations identified, it was first necessary to adjust the annual EDEs reported in the previous section to account for an exposure duration exceeding one year. It is assumed in this assessment that these exposures are received by an individual who resides at the maximum exposure location for 30 years. Therefore, the annual EDEs must be multiplied by a factor of 30. These adjusted lifetime EDEs are given in **Table VIII-2**.

The ICRP provides a risk factor of 0.05 lifetime excess cancer mortalities per Sv (ICRP, 1991). This risk factor was applied by multiplying the adjusted lifetime EDEs in **Table VIII.2** by 1E-06 (to convert units from μSv to Sv) and then by 0.05. The resulting maximum, off-site, excess lifetime cancer mortality risk is 6E-07, considering all units of the DWTF, the Area 612, and the DWTF waste transfer operations, and the Building 612 Size Reduction Unit. The value is the same for both the DWTF general area and the Area 612 general area.

The dominant contributor to this risk is the H-3 emissions from the area sources, and the dominant activity appears to be the waste transfer operations. The emission rate of H-3 for this assessment was derived from the 1994 NESHAPs evaluations (Surano *et al.*, 1995) and is based on monitoring data near the Area 612. However, this monitoring data is not specific for waste transfer operations, but for any operations in the Area 612 vicinity by which H-3 may be released. While it was assumed that all H-3 releases in the vicinity of Area 612 were attributable to waste transfer operations, other sources may be contributing to the releases. The dose and risk estimated here may be overestimates of that posed by the waste transfer operations.

VIII.4   References

International Commission on Radiological Protection (ICRP). 1977. *Recommendations of the International Commission on Radiological Protection*. Publication 26. Pergamon Press, New York, NY.

International Commission on Radiological Protection (ICRP). 1980. *Limits for Intakes of Radionuclides by Workers*. Publication 30. Pergamon Press, New York, NY.

International Commission on Radiological Protection (ICRP). 1991. *1990 Recommendations of the International Commission on Radiological Protection*. Publication 60, Volume 21, No. 1-3. Pergamon Press, New York, NY.

National Council on Radiation Protection (NCRP). 1996. *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground*, Vol. 2. Publication 123, NCRP Publications, Bethesda, Maryland.

Surano, K. A., A. H. Biermann, R. J. Harrach, F. J. Gouveia, R. L. Berger, B. C. Fields, P. J. Tate, and G. M. Gallegos. 1995. *LLNL NESHAPs 1994 Annual Report.* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-ID-113867-95.

U.S. Department of Energy (DOE). 1988. *General Environmental Protection Program*. U.S. Department of Energy, Washington D.C. (DOE Order No. 5400.1).

U.S, Department of Energy (DOE). 1990. *Radiation Protection of the Public and the Environment*. U.S. Department of Energy, Washington, D.C. (DOE Order No. 5400.5).

U.S. Environmental Protection Agency (EPA). 1988). *Clean Air Act Assessment Package—1988, CAP88-PC, Version 1.0*. U.S. Department of the Interior, Environmental Protection Agency, Washington, D.C.

VIII.5   Acronyms

CFR   Code of Federal Regulations

DOE   U.S. Department of Energy

DWTF   Decontamination and Waste Treatment Facility

EDE   Effective Dose Equivalent

EPA   U.S. Environmental Protection Agency

ICRP   International Commission on Radiological Protection

LLNL   Lawrence Livermore National Laboratory

NCRP   National Council on Radiation Protection

NESHAPs   National Emissions Standards for Hazardous Air Pollutants

Table VIII-1. Surrogates Used in Radiological Dose Calculations

Radionuclide Listed in Appendix E	Surrogate Radionuclide Selected
Au-195	Zn-65
Bi-205	Eu-156
Bi-206	Nb-95
Bi-207	Cs-137
Cd-109	Ru-106
Ce-139	Co-57
Cf-249	Am-241
Es-254	Cm-244
Gd-148	Cm-243
Rh-102	Co-60
Se-75	Zn-65
Sr-85	Zr-95
Ta-182	Ru-106
Tl-204	Eu-155
W-188	Zn-65
Y-88	Ag-110m

Table VIII-2. Estimated Maximum Off-Site Radiological Dose and Risk from the DWTF Treatment Units, the Building 612 Size Reduction Unit, and the Area 612 and DWTF Waste Transfer Operations

Treatment Unit & Location	Annual Effective Dose Equivalent (Sv/yr)	Major Radionuclide	Adjusted Lifetime Effective Dose Equivalent (Sv)	Estimated Excess Cancer Mortality
DWTF Stack				
Bleaching Unit	0	—	0	
Centrifuge Unit	1.8E-09	H-3	5.4E-08	
Debris Washer	6.0E-04	C-14	1.8E-02	
Filtration Module	3.9E-05	H-3	1.2E-03	
Shredder/chopper	1.4E-02	H-3	4.2E-01	
Solidification System	4.6E-05	H-3	1.4E-03	
Tank Farm/Blending Unit/ Evaporator	3.1E-06	H-3	9.3E-05	
Water Reactor	2.7E-08	U-238	8.1E-07	
Total DWTF Stack	1.5E-02	H-3	4.4E-01	2E-08
DWTF Transfer Operations	4.1E-01	H-3	1.2E+01	6E-07
Total DWTF	**4.3E-01**	**H-3**	**1.3E+01**	**6E-07**
Building 612 Size Reduction Unit	7.5E-02	H-3	2.3	1E-07
Area 612 Transfer Operations	3.3E-01	H-3	9.9	5E-07
Total Area 612 Facility	**4.1E-01**	**H-3**	**1.2E+01**	**6E-07**
Maximum Off-Site Dose and Risk[a]	**4.3E-01**		**1.3E+01**	**6E-07**

[a] Maximum dose and risk associated with the DWTF and Area 612 Facility are not additive because the air dispersion calculations indicate that the plumes from these two locations do not significantly overlap.

Section IX.
Summary of Human Health Risk Assessment

SECTION IX.   SUMMARY OF HUMAN HEALTH RISK ASSESSMENT

IX.1   Introduction

The objective of this Health Risk Assessment was to evaluate the potential cancer risk and the noncancer health effects associated with the routine operation of waste handling and treatment facilities at the Main Site of Lawrence Livermore National Laboratory (LLNL). This evaluation was based on exposure scenarios developed to characterize potential risks and hazards from chemical releases to individuals who may occupy residences near LLNL ($MEI_{RESreal}$, MEI_{REShyp}); children at a hypothetical daycare center located in the nearest residential neighborhood (MEI_{cdc}); adult workers off site (MEI_{awo}); and adult workers on site (MEI_{aos}). We also evaluated the cancer mortality risk from radionuclide releases to off-site receptors at the location of the maximum effective dose equivalents (EDEs). Risks and/or noncancer hazard indices were calculated for: (1) inhalation exposures to volatile and particulate chemicals, and radionuclide constituents emitted from the Decontamination and Waste Treatment Facility (DWTF) and the Area 612 Facility; and (2) ingestion exposures to chemical and radionuclide particulates emitted from solid waste streams at the DWTF and Area 612 Facility and deposited onto homegrown produce. We used surrogate cancer potency factors (CPFs) and surrogate reference doses (RfDs) to characterize the risk and hazard, respectively, attributable to emissions of chemicals from waste treatment streams which have constituents not otherwise addressed in the Health Risk Assessment.

The incremental lifetime excess cancer risks and chronic noncancer hazard indices calculated for inhalation and/or ingestion of chemicals for each receptor location are summarized in **Table IX-1**. For all MEI receptor locations, the risk of cancer attributable to chemical exposures range from 4×10^{-9} (MEI_{cdc}) to 7×10^{-7} (MEI_{REShyp}). The hazard indices are all less than 1.0, and range from 2.4×10^{-9} to 2.2×10^{-2}.

Lifetime excess cancer mortality risk from radionuclides for hypothetical off-site receptors located in the region of maximum EDEs are summarized in **Table IX-2.**

Acute, noncancer hazards attributable to maximum releases of chemicals of concern (**Section VII**) were evaluated according to procedures specified by the state of California (California Air Pollution Control Officers Association [CAPCOA], 1993; California Environmental Protection Agency, Office of Environmental Health Hazard [CAL/EPA/OEHHA], 1994, and 1995). The results of this evaluation, described in detail in **Section VII**, are summarized in **Table IX-3**. Maximum hourly releases from the DWTF or the Area 612 Facility result in calculated, target-organ-specific exposure ratios less than 1.0. This outcome indicates that it is unlikely that any individual would experience any acute, adverse health effects from short-term exposures to chemicals of concern emitted from either the DWTF or the Area 612 Facility. Note that spatial differences between the DWTF and the Area 612 Facility are considered sufficiently large such that we assumed that maximum, one-hour concentrations at a receptor location are the result of emissions only from an individual facility (i.e., either the DWTF or the Area 612 Facility).

The risks, chronic noncancer hazard indices, and estimates of acute (maximum hourly) exposure are expected to remain within generally acceptable levels during the operational lifetime of the DWTF and the Area 612 Facility and, thus, are are not expected to present unacceptable levels of risk or hazard to the public or workers on site.

IX.2 Uncertainties and Conservatisms

In this assessment, our approach to chemical identification, source-term development, meterological modeling, exposure pathway screening, locating human receptors, and calculating risk and hazard was realistic to the extent possible. However, the degree of realism for some input parameters could not be evaluated because of uncertainties in, or lack of, available data. These input parameters were quantified in a manner that tends to maximize estimated emissions and risks. Thus, the results of this risk assessment are considered to conservatively bound the potential for adverse health effects associated with operation of the DWTF and the Area 612 Facility.

IX.2.1 Uncertainties and Conservatisms in the Source-Term Development

In order to account for any uncertainties in assessment of the source term, we made certain conservative assumptions. A principal uncertainty is related to the precise mass of each chemical in waste streams destined for the various treatment and handling units. Chemical masses or volumes are frequently reported in the Total Waste Management System (TWMS) database (see **Section III**) as being less than a specific percentage (e.g., < 1%). In all such instances, we calculated the chemical mass as if the quantity were equal to the percentage noted. Because the "less than" designation is often a notational convenience on the part of the waste generator to indicate small or trace quantities, our calculations probably over-estimate the amount of chemical present in waste records with this notation. For the DWTF Tank Farm, the summed chemical mass for both 1992 and 1993 were compared, and the maximum chemical mass for either 1992 or 1993 was chosen to represent annual emissions (McDowell-Boyer *et al.*, 1995). For annual-average emissions from the DWTF Tank Farm, the assumption was made that 100% of the mass of all of the chemicals of concern were released to the atmosphere.

A significant conservatism in the development of the source term is found in our approach to designating the physical form of a chemical when specific information on physical form was not available. Specifically, we assumed that all chemicals of unknown physical form are volatile liquids (i.e., L_2 in our nomenclature). An additional major conservatism was our assumption that 100% of chemicals designated as volatile liquids would partition from most wastes. For the Area 612 Facility and DWTF blending/transfer areas, emission rates were calculated assuming volatilization of pure chemical of concern but not volatilization from dilute aqueous solution. All of these assumptions maximize the calculated potential emissions of chemicals from waste treatment processes.

Those chemicals designated as nonvolatile liquids (i.e., L_1 in our nomenclature) present in solid waste streams are assumed to adsorb onto the surface of solids, with subsequent partitioning as particulate matter (**Section III**). This assumption maximizes the calculated emissions of these materials.

Abatement calculations of particulate releases from the DWTF and the Area 612 Facility accounted for all HEPA filters incorporated into the current facility designs. However, we applied an abatement efficiency of 0.99, despite the higher efficiency rating of 0.9997 generally attributed to HEPA filters, thus effectively overestimating particulate releases from waste handling.

For the maximum hourly emissions estimated from the DWTF Tank Farm, and both the DWTF and Area 612 Facility transfer/blending areas, a mass transfer model was used based on a hypothetical blend of waste containing the maximum concentration of each chemical of concern from all blends (McDowell-Boyer *et al.*, 1995). For each of the other waste treatment units, maximum hourly emissions were calculated by constructing a hypothetical waste batch. These waste batches were developed based on the maximum mass of each chemical of interest in a treatment unit's representative waste. All chemical maxima were combined to form a single, hypothetical waste stream, under the assumption that all chemical quantities identified in this manner would be treated simultaneously in a specific unit, with all emissions resulting from that treatment occurring within a one-hour period. Furthermore, it was assumed that all maximum batches would be treated simultaneously in all waste treatment units. This extremely conservative approach almost certainly represents a worst-case estimate of maximum hourly chemical releases.

IX.2.2 Uncertainties and Conservatisms in Calculations of Dose and Risk

Meteorological modeling in this assessment yielded normalized concentrations of chemicals at the receptor locations of interest. These normalized concentrations, based on a unit emission rate, were adjusted to estimate actual chemical concentrations using conservative emission estimates (see **Section IV**). The five-year, annual-average, normalized concentration is representative of realistic, average meteorological conditions and is not especially conservative. However, our modeling takes no credit for plume depletion due to settling or impact of the plume with the ground, despite the fact that settling and plume interception with the ground are considered in deriving soil and vegetation concentrations (see **Section IV**). Furthermore, the estimated normalized, maximum, one-hour concentration is a substantially conservative value to account for meteorological scenarios (wind speed and direction) that are extremely atypical and infrequent during expected times of operation. Accordingly, additional conservatism can be attributed to this particular application of the meteorological model.

The equations used for estimating doses for the MEIs at the exposure points of interest are consistent with accepted practice. However, an adult inhalation rate of 20 m^3/d could overestimate the lifetime average. According to Layton (1993), the lifetime average breathing rate between ages 9 and 75 might more realistically be estimated by a value of 12 m^3/d. The data reported by Layton (1993) also suggest that the childhood average breathing rate between birth and age 6 is less than 10 m^3/d (i.e., as low as 4.5 m^3/d under age 1, and as low as 8.3 m^3/d for children ages 3 to 6). Additionally, the period of residential duration may be less than the 30-year period used in the calculation of residential dose. For example, based on data reported by Israeli and Nelson (1992), only 5% of the population lives in the same residence longer than 23 years. Furthermore, based on a 1.4-year average residence time for all housing categories reported by Israeli and Nelson (1992), it is unlikely that a child would attend the same child

daycare center for an entire 6-year period. Any reduction in one or more of these parameters will result in a reduction in the estimate of corresponding dose and, subsequently, in the determination of the corresponding risk and hazard.

As described earlier in this section, the product of the dose and a CPF is the carcinogenic risk, and the quotient of the dose and the RfD is the hazard index. The CPFs and RfDs published in the regulatory literature are deliberately derived to protect public health. Any conservatism in the estimation of CPF or RfD translates directly into a conservative estimate of the risk or hazard.

To address uncertainties associated with exposure to chemicals designated as "non-specific," or to those chemicals which had no regulatory toxicity values, we assigned representative surrogate exposure-pathway-specific CPFs and RfDs (**Section VI**). These toxicity value assignments address uncertainty due to (1) the possibility that chemicals for which no CPF or RfD is reported could still contribute to potential total excess lifetime cancer risk and potential total noncancer hazard associated with the routine operation of waste treatment facilities at LLNL; (2) the fact that the the identity of constituents entering the waste treatment system do not remain static over time; and (3) the fact that it was not possible to make specific or comprehensive predictions concerning the identity of all possible waste constituents which may be treated or handled at LLNL in the future.

Based on our interpretation of the results, the carcinogenic risk and noncancer hazard for emissions from HWM operations at the DWTF and the Area 612 Facility are expected to be within generally acceptable levels and would not result in an unacceptable level of risk or hazard to the public or workers on site. The level of confidence in these results is reinforced by the substantial conservatism employed in this quantitative analysis, as summarized above.

IX.3   References

California Air Pollution Control Officers Association (CAPCOA). 1993. *Air Toxics "Hot Spots" Program, Revised 1992 Risk Assessment Guidelines*, Toxics Committee of the California Air Pollution Control Officers Association, in consultation with the Air Toxicology Unit, Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment, and the Special Projects Section, Toxic Air Contaminant Identification Branch, Air Resources Board. Sacramento, CA, October.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1994. *Air Toxics "Hot Spots "Program Risk Assessment Guidelines: Part 1, Evaluation of Acute Non-Cancer Health Effects, Draft for Public Comment.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA, December.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (CAL/EPA/OEHHA). 1995. Technical Support Document for The Determination of Acute Toxicity Exposure Levels for Airborne Toxicants, Draft for Public

Comment. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA, January.

Israeli, M., and C.B. Nelson. 1992. "Distribution and Expected Time of Residence for U.S. Households," *Risk Analysis* 12 (1), 65-72.

Layton, D.W. 1993. "Metabolically Consistent Breathing Rates for Use in Dose Assessments," *Health Phys.* 64 (1), 23-26.

McDowell-Boyer, L., J. Daniels, G. Gallegos, F. Gouveia, L. Hall, G. May, T. Kato, J. Huang, and A. Dennis, 1995. *Health Risk Assessment for Hazardous and Mixed Waste Management Units at Lawrence Livermore National Laboratory, 1995* (1995 Health Risk Assessment [HRA]). Environmental Protection Department and Health and Ecological Assessment Division, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-AR-119482.

IX.4 Acronyms

aos   Adult worker off site

awo   Adult worker on site

CAL/EPA   California Environmental Protection Agency

CAPCOA   California Air Pollution Control Officers Association

cdc   child daycare center

CPF   Cancer potency factor

DOE   U.S. Department of Energy

DTSC   Department of Toxic Substances Control

DWTF   Decontamination and Waste Treatment Facility

EDE   Effective Dose Equivalent

EPA   U.S. Environmental Protection Agency

HRA   Health Risk Assessment

LLNL   Lawrence Livermore National Laboratory

MEI   Maximally exposed individual

OEHHA   Office of Environmental Health Hazard Assessment

PEA   Preliminary Endangerment Assessment

PEF   Pathway exposure factor

RES_{hyp} Residence (hypothetical)

RES_{real} Residence (real)

TWMS   Total Waste Management System

Table IX-1. **Summary of incremental lifetime excess cancer risk and noncancer hazard indices from chemicals emitted from the DWTF and Area 612 Facility**

MEI receptor	Incremental lifetime cancer risk	Chronic noncancer hazard indices
MEI_{awo}	3×10^{-8}	4.1×10^{-4}
MEI_{aos}	3×10^{-8}	4.7×10^{-4}
$MEI_{RESreal}$	5×10^{-7}	1.4×10^{-2}
MEI_{REShyp}	7×10^{-7}	2.2×10^{-2}
MEI_{cdc}	4×10^{-9}	2.4×10^{-4}

Table IX-2. **Summary of lifetime excess cancer mortality risk associated with exposures to radionuclides at locations which correspond to maximum EDEs**

Emission source	Exposure location	Lifetime excess cancer mortality risk
DWTF Facility	Maximum EDE for the DWTF	6×10^{-7}
Area 612 Facility	Maximum EDE for Area 612	6×10^{-7}

Table IX-3. Target-organ-specific hazard quotients for maximum hourly chemical releases from the DWTF and the Area 612 Facility

Target organ or system	Total target-organ-specific hazard quotient for the Area 612 Facility	Total target-organ-specific hazard quotient for the DWTF Facility
Central nervous system	4.6×10^{-2}	1.3×10^{-1}
Eye	1.3×10^{-1}	1.5×10^{-1}
Gastrointestinal tract, kidney, and liver	1.5×10^{-2}	2.9×10^{-2}
Immune system and blood	2.1×10^{-2}	1.3×10^{-2}
Reproductive/Developmental	1.4×10^{-1}	1.7×10^{-1}
Respiratory	5.8×10^{-1}	7.2×10^{-1}
Skin	1.8×10^{-8}	1.1×10^{-9}

Supplement A.

Form Codes and Treatment Process Definitions

SUPPLEMENT A. FORM CODES AND TREATMENT PROCESS DEFINITIONS

1.0 Form Codes
(Taken from the U.S. Environmental Protection Agency's [EPA's] Biennial Report)

Code	Waste description	Code	Waste description
	LAB PACKS	B205	Oil-water emulsion or mixture
		B206	Waste oil
Lab packs—Lab packs of mixed wastes, chemicals, lab wastes		B207	Concentrated aqueous solution of other organics
		B208	Concentrated phenolics
		B209	Organic paint, ink, lacquer, or varnish
B001	Lab packs of old chemicals only	B210	Adhesives or epoxies
B002	Lab packs of debris only	B211	Paint thinner or petroleum distillates
B003	Mixed lab packs	B212	Reactive or polymerizable organic liquid
B004	Lab packs containing acute hazardous wastes	B219	Other organic liquids (specify in comments)
B009	Other lab packs (specify in comments)		
			SOLIDS
	LIQUIDS		
		Inorganic solids—Waste that is primarily inorganic and solid, with low organic content and low-to-moderate water content; not pumpable	
Inorganic liquids—Waste that is primarily inorganic and highly fluid (e.g., aqueous), with low suspended inorganic solids and low organic content			
		B301	Soil contaminated with organics
		B302	Soil contaminated with inorganics only
B101	Aqueous waste with low solvents	B303	Ash, slag, or other residue from incineration of wastes
B102	Aqueous waste with low other toxic organics	B304	Other "dry" ash, slag, or thermal residue
B103	Spent acid with metals	B305	"Dry" lime or metal hydroxide solids chemically "fixed"
B104	Spent acid without metals	B306	"Dry" lime or metal hydroxide solids not "fixed"
B105	Acidic aqueous waste	B307	Metal scale, filings, or scrap
B106	Caustic solution with metals but no cyanides	B308	Empty or crushed metal drums or containers
B107	Caustic solution with metals and cyanides	B309	Batteries or battery parts, casings, cores
B108	Caustic solution with cyanides but no metals	B310	Spent solid filters or adsorbents
B109	Spent caustic	B311	Asbestos solids and debris
B110	Caustic aqueous waste	B312	Metal-cyanide salts/chemicals
B111	Aqueous waste with reactive sulfides	B313	Reactive cyanide salts/chemicals
B112	Aqueous waste with other reactives (e.g., explosives)	B314	Reactive sulfide salts/chemicals
		B315	Other reactive salts/chemicals
B113	Other aqueous waste with high dissolved solids	B316	Other metal salts/chemicals
B114	Other aqueous waste with low dissolved solids	B319	Other waste inorganic solids (specify in comments)
B115	Scrubber water		
B116	Leachate		
B117	Waste liquid mercury		
B119	Other inorganic liquids (specify in comments)		
		Organic solids—Waste that is primarily organic and solid, with low-to-moderate inorganic content and water content; not pumpable	
Organic liquids—Waste that is primarily organic and is highly fluid, with low inorganic solids content and low-to-moderate water content			
		B401	Halogenated pesticide solid
B201	Concentrated solvent-water solution	B402	Non-halogenated pesticide solid
B202	Halogenated (e.g., chlorinated) solvent	B403	Solid resins or polymerized organics
B203	Non-halogenated solvent	B404	Spent carbon
B204	Halogenated/non-halogenated solvent mixture		

Code	Waste description	Code	Waste description
B405	Reactive organic solid	B516	Chloride or other brine sludge
B406	Empty fiber or plastic containers	B519	Other inorganic sludges (specify in comments)
B407	Other halogenated organic solids (specify in comments)		
B409	Other non-halogenated organic solids (specify in comments)		

Organic sludges—Waste that is primarily organic with low-to-moderate inorganic solids content and water content, and pumpable

SLUDGES

Inorganic sludges—Waste that is primarily inorganic, with moderate-to-high water content and low organic content, and pumpable

B501	Lime sludge without metals	B601	Still bottoms of halogenated (e.g., chlorinated) solvents or other organic liquids
B502	Lime sludge with metals/metal hydroxide sludge	B602	Still bottoms of non-halogenated solvents or other organic liquids
B503	Wastewater treatment sludge with toxic organics	B603	Oily sludge
B504	Other wastewater treatment sludge	B604	Organic paint or ink sludge
B505	Untreated plating sludge without cyanides	B605	Reactive or polymerizable organics
B506	Untreated plating sludge with cyanides	B606	Resins, tars, or tarry sludge
B507	Other sludge with cyanides	B607	Biological treatment sludge
B508	Sludge with reactive sulfides	B608	Sewage or other untreated biological sludge
B509	Sludge with other reactives	B609	Other organic sludges (specify in comments)
B510	Degreasing sludge with metal scale or filings		
B511	Air pollution control device sludge (e.g., fly ash, wet scrubber sludge)		

GASES

Inorganic gases—Waste that is primarily inorganic with a low organic content and is a gas at atmospheric pressure

B512	Sediment or lagoon dragout contaminated with organics	B701	Inorganic gases
B513	Sediment or lagoon dragout contaminated with inorganics only		

Organic gases—Waste that is primarily organic with low-to-moderate inorganic content and is a gas at atmospheric pressure

B514	Drilling mud	B801	Organic gases
B515	Asbestos slurry or sludge		

2.0   Treatment Process Definitions

Absorption—Molecular Sieve (T48) is a process using synthetic absorbents made of crystalline aluminosilicates or aluminophosphates that have undergone heating to remove water of hydration. These absorbents possess high porosity and have uniform-sized pores with molecular dimensions. Because of the small and uniform pore sizes, only small molecules are selectively absorbed based on molecular shape. Molecular sieves have particular affinity for unsaturated and polar molecules and are primarily used in gas treatment, but are also effective for removing water from organic liquids. At higher temperatures (usually above 400°F), chemical reactions or bonding may occur, resulting in chemisorption. Molecular sieve absorption will be restricted to small scale treatment.

Activated Carbon (T49) will be used to adsorb organic and, to a lesser extent, dissolved metal and other inorganic contaminants. Activated carbon will be used to treat both aqueous and gaseous waste streams as follows.

- Powdered activated carbon (PAC) will be loosely added to waste waters containing dissolved organics at concentrations of less than 5 percent, and to waste waters containing metal complexes. The additions will occur in either the tank farm or the waste blending station. The spent PAC with the adsorbed contaminants will be physically separated from the waste water for subsequent treatment and disposal. For example, PAC will be used to adsorb organic sulfides or dissolved organics (i.e., benzene) for removal as a precipitate.

- Granular activated carbon (GAC) will be placed in packed beds (e.g., carbon column) to remove organic contaminants from off-gases that are emitted from the treatment processes. Because the adsorptive properties of each contaminant varies, an indicator parameter (e.g., total organic carbon) is frequently used to detect substantial changes in the adsorption rate of the packed bed.

Activated Sludge (T67) is a waste water treatment process used to aerobically decompose organic compounds. The sludge consists of biological flocculant growths that form within the waste water. The sludge provides a surface that is suitable for biological oxidation. The organic material and oxygen from the aeration process serve as the food source for the micro-organisms. With sufficient retention time for biological reaction, ample supply of oxygen, and readily degradable organic matter, activated sludge is a very effective method for treating waste waters with organic compounds. Total organic carbon is often used as an indicator parameter for the biodegradation of many organic constituents that cannot be directly analyzed in waste water residues. Activated sludge will be restricted to small scale treatment.

Adsorption—Gas (T34C) is used to remove specific contaminants from off-gases from the venting of treatment equipment, or to capture compressed gases from venting gas cylinders. Gas adsorption is one of the Land Disposal Restriction-(LDR) mandated treatment standards for ignitable compressed gases (D001), fluorine (P056), nitric oxide (P076), nitrogen dioxide (P078), and hydrogen fluoride (U134). Per the LDR treatment standard provided in 22 CCR 66268, Table 1, gas adsorption is the venting of compressed gases into an adsorbing or reacting media

(i.e., solid or liquid). In the adsorption process, the contaminants or gases penetrate into the inner structure of the solid or liquid adsorbing media. The contaminants or gases may also chemically react with the adsorbing media to form stable bonds. Scrubbing is a form of adsorption that will be commonly used for treating hazardous waste gases at LLNL. The adsorbents include molecular sieves (see treatment process code T48). If required, the spent adsorbing media can easily be subjected to further treatment prior to final disposal. The adsorption of hazardous waste gases from compressed cylinders will be restricted to small scale treatment and the gas adsorption system.

Aerobic/Anaerobic Tank (T69) is used to degrade organics or nonmetallic inorganics that contain phosphorous, nitrogen, and sulfur in a tank that is operated under either aerobic or anaerobic conditions. Like Activated Sludge (T67), this treatment process uses micro-organisms to degrade the specific contaminants. Naturally occurring micro-organisms, such as bacteria, fungi, or yeast, are used to degrade harmful chemicals into less toxic or non-toxic compounds consisting mainly of carbon dioxide, water, and fatty acids. Nutrients and other compounds may be added to enhance the biological growth and activity of the micro-organisms. Degradation within aerobic or anaerobic tanks will be restricted to small scale treatment.

Air Stripping—See Stripping (T64).

Amalgamation (T34A) is the conversion of liquid, elemental mercury into a non-liquid, semi-solid amalgam that is easier to manage and suitable for land disposal. The potential for mercury vapor emissions and leaching of mercury to water supplies is significantly reduced. Inorganic chemical reagents such as copper, zinc, nickel, gold, and sulfur are used to amalgamate mercury. Amalgamation is suitable for treating wastes containing mercury, especially radioactive mercury isotopes. The amalgamation process will be restricted to small scale treatment.

Biodegradation—See Aerobic/Anaerobic Tank (T69).

Blending (T50) is used to mix small batches of compatible wastes together to form a larger batch for subsequent treatment. The blending process reduces the relative hazards of the unblended wastes (e.g., ignitability) and pre-treats the waste by combining the unblended waste in a manner that produces beneficial chemical reactions (e.g., neutralization).

Carbon Adsorption—See Activated Carbon (T49).

Catalysis (T51) generally refers to chemical processes in which chemical reaction rates are subjected to the influence of a catalyst. Catalysts are used to form an intermediate compound or surface orientation/binding that allows the desired reaction products to be formed, or to increase the reaction rate or yield. Although the catalyst may change chemically during the intermediate reaction, it is regenerated as part of the overall reaction process. The use of catalysts will be restricted to small scale treatment using a pressure reactor.

Centrifugation (T35) is used to separate multiphasic wastes into different phases based on differences in densities. In lieu of gravity settling, centrifuges are rotated at high speeds to induce a strong centrifugal force on the waste. The centrifuge will primarily be used to remove

radioactive solid components, separate immiscible liquids, or to pre-treat waste for subsequent treatment processes.

Chemical Fixation (T21) is the use of a chemical reagent to increase the durability or stability of the waste to resist long-term leaching and decomposition. Fixatives may be used to aid precipitation or to chemically stabilize specific types of waste.

Chemical Oxidation (T22) is the raising of metal oxidation states to facilitate the removal of contaminants by subsequent treatment processes, such as precipitation, or to chemically convert the hazardous contaminants into non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidation reagents that may be used include, but are not necessarily limited to: peroxides, hypochlorite (e.g., bleach), chlorine, chlorine dioxide, ozone, persulfates, perchlorates, and permanganates. These reagents may be used in combination or with ultraviolet light to improve the treatment effectiveness. For example, hydrogen peroxide will be used to oxidize monovalent copper. Hypochlorite is proposed to be used to oxidize uranium mill turnings to eliminate the pyrophoric properties of this material. Chemical reagents will also be used to break down emulsions by oxidizing organic molecules. For example, hydrogen peroxide will be used to reduce the viscosity of oily waste to facilitate subsequent treatment processes.

Chemical Precipitation (T23) is used to transform dissolved metals and other inorganics into insoluble mass that can be removed from waste waters via the evaporator, centrifuge, or filtration module. The chemical reagents that may be used include, but are not necessarily limited to: lime that either contains calcium and/or magnesium oxides and/or hydroxides; caustic solutions including sodium and/or potassium hydroxides; soda ash (i.e., sodium carbonate); sodium sulfide; ferric sulfate; ferric chloride; alum; and sodium sulfate. Flocculating, coagulating or similar reagents/processes that enhance sludge dewatering characteristics may be used in conjunction with the precipitation chemical reagents.

Chemical Reduction (T24) is the lowering of metal oxidation states to facilitate the removal of contaminants by subsequent treatment processes, such as precipitation, or to chemically convert the hazardous contaminants into non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The reducing reagents that may be used include, but are not necessarily limited to: sulfur dioxide; sodium, potassium, or alkali salts of sulfites, bisulfites, metabisulfates, and polyethylene glycols; sodium hydrosulfite; and ferrous salts. These reagents may be used in combination or with ultraviolet light to improve the treatment effectiveness. For example, ferrous sulfate will be used to reduce hexavalent chromium to its less toxic trivalent state.

Chlorination (T25) is typically used to oxidize chemical compounds (see chemical oxidation [T22]), kill bacteria, and is routinely included in secondary waste water treatment for odor control and disinfecting. Chlorine will typically be used at LLNL for oxidation.

Clarification (T36) will occur within the DWTF Tank Farm to decant clean water which is discharged to the sewer from the portion of the waste water containing the settled suspended solids. As such, clarification serves to pre-treat the waste water containing suspended solids or colloidal matter prior to physical separation via the evaporator, centrifuge, or filtration module. Unlike precipitation, chemical reagents are not used in the clarification process. Clarification will

typically be performed in conjunction with coagulation and flocculation (see process definitions for T37 and T41).

Coagulation (T37) is the irreversible combination or aggregation of semi-solid particles to form a larger mass. Electrolytes will typically be added to waste waters to coagulate fine particles together to allow physical removal of the contaminants. Waste waters may also be heated or cooled to initiate coagulation.

Controlled Water Reaction (T34B) is used to safely deactivate water-reactive substances. The basic principle of this treatment process is to slowly introduce water into a reactor that contains the water-reactive waste. An inert atmosphere will also typically be maintained within the reactor to prevent ignition of the water-reactive waste and/or detonation of hydrogen gases that are typically formed as a reaction byproduct. Because these reactions can be very exothermic, supplemental cooling may also be required. Water-reactive materials include alkali and earth alkali metals, their hydrides, oxides, and methoxides. Many anhydrous liquids and gases, such as acetic anhydride and hydrogen sulfate, are also considered to be water-reactive. Controlled water reactions will be conducted in the water reactor and restricted to small scale treatment.

Cyanide Destruction (T27) is used convert toxic cyanide salts into harmless or less toxic constituents. For example, bleach or hydrogen peroxide are typically used to treat unreacted cyanide salts if present in waste waters.

Deactivation is an LDR-mandated treatment standard for ignitable, corrosive, and reactive waste. Any treatment process that eliminates or destroys the above-mentioned hazardous waste characteristics is considered to be deactivation. Although deactivation is not a stand-alone treatment process, it is being listed for completeness because ignitable, corrosive, and reactive waste will be treated and subjected to the LDR deactivation treatment standard.

Decanting (T38) is used to remove a low-density layer that floats on top of a high-density layer. For example, a floating oil layer will be separated from waste waters or chlorosolvents in the DWTF Tank Farm by decanting or skimming. Chemical reagents may also be used to aid the separation process. For example, monoethanolamine-bearing wastes will be acidified to separate oil from water. Decanting will also be used in conjunction with clarification to obtain a waste water that is suitable for discharge to the sanitary sewer.

Decontamination—See Size Reduction (T47A).

Degradation (T28) is the breakdown of a high-molecular-weight polymeric material into several less toxic or easy to treat substances that have lower molecular weights. Degradation can occur by exposing the polymeric material to sunlight, heat, oxidation, solvents, or micro-organisms. Degradation of compounds will be restricted to small scale treatment.

Detoxification (T29) is any treatment process that eliminates a toxic property of a waste stream.

Dialysis (T53) is used to selectively separate low-molecular-weight solutes that can easily diffuse through a semi-permeable membrane from colloidal and high-molecular-weight solutes

that will not readily pass through the membrane. Concentration and/or pressure differences on opposite sides of the membrane provide the driving force for the diffusion process. The primary purpose of dialysis is for the final purification of a waste water to allow discharge to the sanitary sewer.

Distillation (T54) is used to purify a liquid through evaporation and condensation. The product is collected from the condenser. The cold vapor evaporator will be used to obtain "purified" water that is suitable for discharge to the sanitary sewer. Also see Evaporation (T57).

Drying (T66A) is used to eliminate free liquids from washed debris to allow packaging for off-site land disposal.

Electrodialysis (T55) is used remove ionic compounds by imposing an electrical current across a semi-permeable membrane. Electrodialysis is a form of dialysis that utilizes the potential differences of the electrical currents as the driving force for the separation process. For example, ion-exchange membranes, which are alternate layers of cation- and anion-permeable membranes operated under an applied electric current, can be used to deionize water. Anions pass through the anion-permeable membranes, but are prevented from migrating by the cation-permeable membranes. Similarly, cations pass through the cation-permeable membrane, but are retarded by the anion-permeable membrane. Only ionic species can be separated by this method and will be restricted to small scale treatment.

Electrolysis (T56) is used to replace toxic ionic substances in a waste water with non-toxic ionic substances by passing an electrical current through the waste water. The positive and negative ions are carried by the current to the oppositely-charged electrode where they are collected or released. Ions that deposit on the electrode form a coating, thus allowing the contaminants to be physically removed from the solution with the electrode. The use of electrolysis will be restricted to small scale treatment.

Encapsulation (T39) is used to physically and chemically bind contaminants to produce a stable solid material. Various chemical reagents can be used to coat or seal waste contaminants in a durable, non-toxic substance to reduce the leaching and mobility of the contaminants. Various encapsulation processes (e.g., macroencapsulation and stabilization) are specified for the treatment of LDR-restricted waste. Solidification is also included as an encapsulation process. Each of these treatment processes are defined below.

- Macroencapsulation is the application of surface-coating materials such as polymeric organics (e.g., resins and plastics) or a jacket of inert inorganic materials to substantially reduce surface exposure to potential leaching. As stated in 22 CCR 66268, Table 1, macroencapsulation does not include any material that would be classified as a tank or container according to 40 CFR 260.10.

- Stabilization, also called microencapsulation, describes a broad class of treatment processes that immobilize hazardous constituents in a waste. The stabilizing reagents that may be used include, but are not necessarily limited to: Portland cement and lime/pozzolans (e.g., fly ash and cement kiln dust). Other reagents (e.g., iron salts,

silicates, and clay) may be added to enhance the set/cure time and/or compressive strength, or to reduce the overall leachability of the hazardous constituents.

- Solidification is used to solidify free liquids while immobilizing waste constituents through stabilization.

Evaporation (T57) is used to remove dissolved and suspended solids from a waste stream by evaporating water from the waste stream. The "clean" water is condensed and tested to verify that it can be discharged to the sanitary sewer. The concentrated contaminants will typically be subjected to additional treatment (e.g., solidification).

Filtration (T40) is used to separate suspended solids from a liquid by forcing the mixture through a porous barrier (e.g., filter media). The various filter media that may be used include, but are not necessarily limited to: polypropylene cartridge filters; adsorption cartridges consisting of activated carbon or clay-anthracite; cross-flow membrane diffusion filters; cross-flow nanofilters; and reverse osmosis membrane filters. Dialysis (see process description for T53) is also considered a filtration process.

Flocculation (T41) is the combination or aggregation of suspended colloidal particles to form small clumps or tufts. Unlike coagulation, flocculation can often be reserved by agitation because the cohesive forces are relatively weak. This treatment process will be used to accelerate settling for clarification of waste waters, and to improve the effectiveness of filtration. The flocculants that may be used include, but are not necessarily limited to: lime, alum, alumina, ferric chloride, ferric sulfate, or high-molecular-weight polyelectrolytes. For example, colloidal hydroxides and suspended colloids will be flocculated with ferric sulfate and alumina, respectively.

Immobilization—See Encapsulation (T39).

Ion Exchange (T30) is used to replace toxic ions in a waste water with non-toxic ions from a solid ion-exchange resin. In this treatment process, the waste water passes through a packed column of the ion-exchange resin or the resin is added directly to the waste water in a tank. The solid resin with the toxic ions can be easily removed from the treated waste water through filtration if required. The principal mixed-waste application of this process is to recover radionuclides from waste waters or acid leach liquors by using cation-exchange resins or chelating agents.

Leaching (T59), also known as chemical or solvent extraction, is the extraction of a soluble solid into a liquid phase. This is most often done by acids, basic solutions, surfactants, chelators, or organic solvents. Typically, the solubility of the contaminant increases with increasing temperature of the extraction fluid. Chemical extraction is a specified process for treating debris, and will be carried out in the debris washer.

Liquid Ion Exchange (T60) is similar to ion exchange (see treatment process definition for T30), but a liquid substance is used instead of resin as the exchange media. Liquid ion exchange is used to remove contaminants from solid or gaseous waste streams. The use of liquid ion exchange will be restricted to small scale treatment.

Liquid-Liquid Extraction (T61) is used to extract a contaminant from a liquid waste into an immiscible solvent that has a greater solvent affinity for the contaminant. Decanting is typically used to separate the liquid waste from contaminant-bearing immiscible solvent. The spent solvent can be incinerated or recovered following the extraction process. This process will be restricted to small scale treatment.

Macroencapsulation—See Encapsulation (T39).

Metals Recovery is an LDR-mandated treatment standard for specific waste streams. Per the LDR treatment standard provided in 22 CCR 66268, Table 1, metal recovery is not a stand-alone treatment process but includes: ion exchange, resin or solid (i.e., zeolites) adsorption, reverse osmosis, chelation/solvent extraction, freeze crystallization, ultrafiltration, and/or simple precipitation (i.e. crystallization). Although metal recovery does not have a specific treatment code, it is being listed for completeness because some waste managed at LLNL will be subjected to this LDR treatment standard.

Microencapsulation—See Encapsulation (T39).

Neutralization (T31) is the mixing of acid and caustic solutions together to achieve in a pH greater than 2 but less than 12.5, thus eliminating the corrosive characteristic (D002). The neutralization reagents that may be used include, but are not necessarily limited to: acids (e.g., sulfuric acid), bases (e.g., sodium hydroxide), or other waste waters. To meet sanitary sewer discharge requirements, the objective of the neutralization process is to obtain a treated solution that has a pH near 7.

Ozonation (T32) is a process for oxidizing waste with ozone. Ozone (O_3) is an unstable, allotropic form of oxygen that is a very strong oxidant. The oxidation potential of ozone is higher than that of permanganate, hydrogen peroxide, or hypochlorite. As such, ozone is frequently used to oxidize many dissolved organic compounds and other toxic substances. For example, phenolic compounds can be converted to carbon dioxide, water, and less toxic or biodegradable compounds in a cost-effective manner using ozone at concentrations of 1.5 to 2.5 parts ozone per part of phenol. Excess ozone is typically used to ensure that toxic intermediate reaction products are not generated. Ultraviolet radiation used in conjunction with ozone is highly effective for degrading malathion, DDT, pentachlorophenol, dichlorobutane, dichlorobenzene, PCBs, and chloroform.

Photolysis (T33) is a process that uses radiant energy to decompose a compound into simpler components. For example, hydrogen iodide photo-decomposes by the reaction shown below.

$$2HI + h\nu \ \text{--------->} \ H_2 + I_2$$
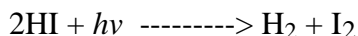
Photolysis is suitable for treating aldehydes, ketones, azo compounds, and organometallic compounds. Catalyst are also typically used in conjunction with photolysis. The use of photolysis will be restricted to small scale treatment.

Retorting (T47C) is a process of distilling compounds using a simple apparatus that consists of a cylindrical vessel with a small-diameter neck bent at a downward angle. Retorting will primarily be used to recover mercury from amalgams, and will be restricted to small scale treatment.

Reverse Osmosis (T62) is used to transfer a pure liquid (usually water) through a semi-permeable membrane from a concentrated waste solution to a dilute product solution. In this process, the volume of the concentrated waste solution is reduced, and the dilute product solution is free of contaminants to allow discharge to the sanitary sewer. To reverse the normal osmotic flow (e.g., dilute solution to the highly concentrated solution), a pressure differential greater than the osmotic pressure must be maintained across the membrane.

Sedimentation (T44) is the separation of suspended solids and liquids using gravitational settling. This process will be used to obtain a "clean" supernatant and slurry that contains the suspended solids. After settling, the supernatant can be decanted from the slurry. Alternatively, the slurry can be pumped through the bottom of the tank via the thickening process. Sedimentation will primarily be used as a pre-treatment process, and is a very simple and cost-effective method to remove coarse or dense suspended solids from waste waters.

Segregation (T47B) is the manual separation of waste materials into multiple homogeneous waste streams to facilitate handling, storage, treatment, transportation, and/or disposal. Segregation will be used to isolate materials that require special treatment or handling to comply with regulatory requirements or waste acceptance criteria. For example, mixed waste may be segregated from non-radioactive hazardous waste to allow off-site shipment.

Size Reduction (T47A) is used to minimize the volume of waste managed on site or shipped off site. Size reduction includes processes to densify waste materials (e.g., compactors, balers, crushers, shredders, choppers, cutting, and disassembly). For example, the drum crushers located in Building 612 will be used to compact empty, nonreusable drums and containers that contained hazardous or mixed waste to minimize void space. The shredder and chopper (Building 695) will be used to size reduce solid waste to improve the treatment effectiveness of the debris washer or solidification system. Other bulk items, such as equipment with contamination that exceeds safe handling and/or disposal limits, will be manually disassembled and, if required, decontaminated for reuse, maintenance, segregation, and/or off-site disposal. Common hand and power tools will be used in the disassembly process. Decontamination techniques include, but are not limited to, wiping with cloths, vacuuming, water/solvent washing, abrasive blasting, and rinsing. When required, the disassembly and decontamination operations will be conducted within a containment enclosure to prevent the release of airborne particles and liquids to other work areas and the environment.

Solvent Extraction—See Leaching (T59).

Solvent Recovery (T63) is the purification and separation of spent organic solvents for further reuse. Per the LDR treatment standard provided in 22 CCR 66268, Table 1, solvent recovery is not a stand-alone treatment process, but includes: distillation, thin film evaporation, steam stripping, carbon adsorption, critical fluid extraction, liquid-liquid extraction, precipitation with

crystallization (including freeze crystallization), and chemical phase-separation techniques (i.e., addition of acids, bases, demulsifiers, or similar chemicals). The recovery of solvents will be restricted to small scale treatment.

Stabilization—See Encapsulation (T39).

Steam Stripping—See Stripping (T64).

Stripping (T64) is used to remove or "strip" volatile organic compounds (VOCs) from waste waters. Typically air or steam are used as the stripping media, and are forced through the waste water under pressure. Because the vapor pressure of VOCs are less than the waste water, they will volatilize into the air or vapor steam. At LLNL, compressed air will normally be used as the stripping media. The process will normally be conducted by inserting a portable sparging unit into a portable tank at the Waste Blending Station. The off-gases from this treatment process will be vented to the Gas Adsorption System which consists of a carbon adsorption unit capable of removing the volatilized organics from the sparging air stream.

Thickening (T45) is used in conjunction with sedimentation to concentrate suspended solids in a slurry or sludge. Typically, waste waters containing suspended solids will be allowed to gravity separate into a "clean" supernatant and slurry/sludge that contains the suspended solids. The tanks are designed with conical bottoms, which allows the thickened slurry/sludge to be removed from the "clean" supernatant.

Trickling Filter (T75) is a bed of course material used to support biological growth. The waste water is intermittently sprayed on top of the course material and allowed to trickle through the bed. Organic materials from the waste water collect on the surface of the course material where it is oxidized and removed by the micro-organisms. The treated waste water from the filter is free of the organic material. Use of trickling filters will be restricted to small scale treatment.

Ultrafiltration (T46) is a separation process used to remove colloidal and very small-diameter particulates through microporous filters or semi-permeable membranes. The membrane is always microporous and solvent transport is by a viscous-flow mechanism through the membrane pores. A hydraulic pressure differential on the order of several atmospheres is used as the driving force for the filtration process. Ultrafiltration resembles ordinary filtration, differing mainly by the size of the substances captured in the filter media. Ultrafiltration is used primarily to remove dissolved or suspended macromolecule species that exhibit small osmotic pressures.

Water Washing—See Leaching (T59).

References

22 *California Code of Regulations* (CCR) (1995), Title 22, *Social Security*, Health and Welfare Agency, State of California, Sacramento, CA.

40 *Code of Federal Regulations* (CFR) (1995), Title 40, *Protection of the Environment,* Office of the Federal Register, Washington, D.C.

Supplement B.

Dispersion Model Input Data and Sample of Meteorological Data

SUPPLEMENT B. DISPERSION MODEL INPUT DATA AND SAMPLE OF METEOROLOGICAL DATA

Table of Contents

SUPPLEMENT B. DISPERSION MODEL INPUT DATA AND SAMPLE OF METEOROLOGICAL DATA

1.0   Introduction

This appendix consists of several files used to run the ISC-ST3 dispersion model for the current project. The model requires input data from several sources. The portion directing ISC-ST3 to include the building wake effect must be created by the Building Profile Input Program (BPIP).

respectively. The corresponding output files follow the input files in **Sections 3** and **5**. Twelve lines from these output files, complete with keywords for ISC-ST3, are included in the ISC-ST3 input files.

The input files for the ISC-ST3 dispersion model appear below as **Sections 6** and **7**. Lines starting with a double asterisk (**) are comment lines and are ignored by the model. The bulk of these input files is dedicated to specification of elevations of the numerous receptor locations. Meteorological data is also necessary and a sample of the five years of data is included in **Section 8**.

2.0   Building Wake Effect Input File for DWTF Stack

```
'BPIP DWTF case - one stack, 5 buildings'
'ST'
'Meters' 1.0
'UTMN',   0.
5
'B695' 1 0.0
4 13.0
        0.      0.
        0.      -65.5
```

```
        -36.6   -65.5
        -36.6   0.
'TrkBay' 1 0.0
4 7.50
        -4.6    15.2
        -4.6    0.
        -32.0   0.
        -32.0   15.2
'SolidWst' 1 0.0
4 11.8
        9.1     29.0
        9.1     15.2
        -32.0   15.2
        -32.0   29.0
'RadWaste' 1 0.0
4  6.9
        45.7    29.0
        45.7    15.2
        9.1     15.2
        9.1     29.0
'B693' 1 0.0
4  6.1
        53.3    -16.8
        53.3    -62.8
        29.0    -62.8
        29.0    -16.8
1
'StkDWTF'  0.0  20.0  0.0  0.0
0
```

3.0   BPIP Output File for DWTF Stack

BPIP (Dated: 95086)
DATE : 8/27/96
TIME : 13: 4:44
BPIP DWTF case - one stack, 5 buildings

 ===========================
 BPIP PROCESSING INFORMATION:
 ===========================

The ST flag has been set for processing for an ISCST2 run.
Inputs entered in Meters will be converted to meters using a conversion factor of 1.0000. Output will be in meters.

UTMP is set to UTMN. The input is assumed to be in a local X-Y coordinate system as opposed to a UTM coordinate system. True North is in the positive Y direction. Plant north is set to .00 degrees with respect to True North.

 BPIP DWTF case - one stack, 5 buildings

PRELIMINARY* GEP STACK HEIGHT RESULTS TABLE
(Output Units: meters)

	Stack-Building		Preliminary	
Stack Name	Stack Height	Base Elevation Difference	EQNI GEP**	GEP Stack Height Value
StkDWTF	20.00	.00	32.50	65.00

*   Results are based on Determinants 1 & 2 on pages 1 & 2 of the GEP Technical Support Document. Determinant 3 may be investigated for additional stack height credit. Final values result after Determinant 3 has been taken into consideration.

**   Results were derived from Equation 1 on page 6 of GEP TechnicalSupport Document. Values have been adjusted for any stack-building base elevation differences.

Note: Criteria for determining stack heights for modeling emission limitations for a source can be found in Table 3.1 of the GEP Technical Support Document.

BPIP (Dated: 95086)
DATE : 8/27/96
TIME : 13: 4:44

 BPIP DWTF case - one stack, 5 buildings

BPIP output is in meters

```
    SO BUILDHGT StkDWTF  13.00  13.00  13.00  13.00  13.00  13.00
    SO BUILDHGTStkDWTF   13.00  13.00  13.00  13.00  13.00  13.00
    SO BUILDHGT StkDWTF  13.00  13.00  13.00  13.00  13.00  13.00
    SO BUILDHGT StkDWTF  13.00  13.00  13.00  13.00  13.00  13.00
    SO BUILDHGT StkDWTF  13.00  13.00  13.00  13.00  13.00  13.00
    SO BUILDHGT StkDWTF  13.00  13.00  13.00  13.00  13.00  13.00
    SO BUILDWID StkDWTF  47.42  56.80  64.45  70.14  73.70  75.02
    SO BUILDWID StkDWTF  74.07  70.86  65.50  70.86  74.07  75.02
    SO BUILDWID StkDWTF  73.70  70.14  64.45  56.80  47.42  36.60
    SO BUILDWID StkDWTF  47.42  56.80  64.45  70.14  73.70  75.02
    SO BUILDWID StkDWTF  74.07  70.86  65.50  70.86  74.07  75.02
    SO BUILDWID StkDWTF  73.70  70.14  64.45  56.80  47.42  36.60
```

4.0   Building Wake Effect Input File for Building 612 Stack

'BPIP B612 case - one stack, 1 building'
'ST'
'Meters' 1.0

```
'UTMN',  0.
1
'B612' 1 0.0
4  7.6
        12.2      9.6
        12.2     -9.6
        -12.2    -9.6
        -12.2     9.6
1
'StkB612'  0.0  10.0  0.0  0.0
0
```

5.0 BPIP Output File for Building 612 Stack

BPIP (Dated: 95086)
DATE : 1/30/97
TIME : 15:33:41
BPIP B612 case - one stack, 1 building

```
  =============================
 BPIP PROCESSING INFORMATION:
  =============================
```

The ST flag has been set for processing for an ISCST2 run. Inputs entered in Meters will be converted to meters a conversion factor of 1.0000. Output will be in meters.

UTMP is set to UTMN. The input is assumed to be in a X-Y coordinate system as opposed to a UTM coordinate system. True North is in the positive Y direction. Plant north is set to .00 degrees with respect to True North.

BPIP B612 case - one stack, 1 building

PRELIMINARY* GEP STACK HEIGHT RESULTS TABLE
(Output Units: meters)

	Stack-Building		Preliminary	
Stack Name	Stack Height	Base Elevation Difference	EQNI GEP**	GEP Stack Height Value
StkB612	10.00	.00	19.00	65.00

* Results are based on Determinants 1 & 2 on pages 1 & 2 of the Technical Support Document. Determinant 3 may be investigated for additional stack height credit. Final values result after Determinant 3 has been taken into consideration.

** Results were derived from Equation 1 on page 6 of GEP Technical Support Document. Values have been adjusted for any stack-building base elevation differences.

Note: Criteria for determining stack heights for modeling emission for a source can be found in Table 3.1 of the GEP Technical Support Document.

BPIP (Dated: 95086)
DATE : 1/30/97
TIME : 15:33:41

BPIP B612 case - one stack, 1 building

BPIP output is in meters

```
   SO BUILDHGT StkB612    7.60    7.60    7.60    7.60    7.60    7.60
   SO BUILDHGT StkB612    7.60    7.60    7.60    7.60    7.60    7.60
   SO BUILDHGT StkB612    7.60    7.60    7.60    7.60    7.60    7.60
   SO BUILDHGT StkB612    7.60    7.60    7.60    7.60    7.60    7.60
   SO BUILDHGT StkB612    7.60    7.60    7.60    7.60    7.60    7.60
   SO BUILDHGT StkB612    7.60    7.60    7.60    7.60    7.60    7.60
   SO BUILDWID StkB612   27.36   29.50   30.73   31.03   30.39   28.83
   SO BUILDWID StkB612   26.39   23.15   19.20   23.15   26.39   28.83
   SO BUILDWID StkB612   30.39   31.03   30.73   29.50   27.36   24.40
   SO BUILDWID StkB612   27.36   29.50   30.73   31.03   30.39   28.83
   SO BUILDWID StkB612   26.39   23.15   19.20   23.15   26.39   28.83
   SO BUILDWID StkB612   30.39   31.03   30.73   29.50   27.36   24.40
```

6.0   ISC-ST3 Input File for the Two Stack Sources

CO STARTING
  TITLEONE Running the ISC3-ST model for DWTF Project

** Regulatory default options, Rural dispersion, Concentrations at receptors
** Averaging periods for max and average will be 1 hour and the entire year.
** Building height and width are entered for downwash.
** The pollutant is a unit source so that concentrations will be Chi/Q
** List of errors will be written to ERRORS.OUT

  MODELOPT DFAULT RURAL CONC WETDPLT DRYDPLT
**   Find maximum hour (1) and whole-period concentrations

```
      AVERTIME  1       PERIOD
**        Use unit source
   POLLUTID  Unit
**        Specify all heights for sources and receptors
   TERRHGTS  ELEV
**        Please run the model after checking this input file
   RUNORNOT  RUN
**        List of errors will be written to ERRORS.OUT
   ERRORFIL  ERRORS.OUT
CO FINISHED

SO STARTING

** The DWTF Stack
**          name  type    X    Y    Z
   LOCATION  DWTF  POINT  14791  72403  185
**          name  rate  height(m)  temp(K)  veloc(m/s)  diam(m)
   SRCPARAM  DWTF  1.0    20.     293.        10.9      1.98

   BUILDHGT DWTF   13.00  13.00  13.00  13.00  13.00  13.00
   BUILDHGT DWTF   13.00  13.00  13.00  13.00  13.00  13.00
   BUILDHGT DWTF   13.00  13.00  13.00  13.00  13.00  13.00
   BUILDHGT DWTF   13.00  13.00  13.00  13.00  13.00  13.00
   BUILDHGT DWTF   13.00  13.00  13.00  13.00  13.00  13.00
   BUILDHGT DWTF   13.00  13.00  13.00  13.00  13.00  13.00
   BUILDWID DWTF   47.42  56.80  64.45  70.14  73.70  75.02
   BUILDWID DWTF   74.07  70.86  65.50  70.86  74.07  75.02
   BUILDWID DWTF   73.70  70.14  64.45  56.80  47.42  36.60
   BUILDWID DWTF   47.42  56.80  64.45  70.14  73.70  75.02
   BUILDWID DWTF   74.07  70.86  65.50  70.86  74.07  75.02
   BUILDWID DWTF   73.70  70.14  64.45  56.80  47.42  36.60

** The 612 Stack
**          name  type    X    Y    Z
   LOCATION  S612  POINT  14739  71192  198
**          name  rate  height(m)  temp(K)  veloc(m/s)  diam(m)
   SRCPARAM  S612  1.0    10.     293.     16.2       0.61

   BUILDHGT S612   7.60    7.60    7.60    7.60    7.60    7.60
   BUILDHGT S612   7.60    7.60    7.60    7.60    7.60    7.60
   BUILDHGT S612   7.60    7.60    7.60    7.60    7.60    7.60
   BUILDHGT S612   7.60    7.60    7.60    7.60    7.60    7.60
   BUILDHGT S612   7.60    7.60    7.60    7.60    7.60    7.60
   BUILDHGT S612   7.60    7.60    7.60    7.60    7.60    7.60
   BUILDWID S612  27.36   29.50   30.73   31.03   30.39   28.83
   BUILDWID S612  26.39   23.15   19.20   23.15   26.39   28.83
```

```
BUILDWID  S612  30.39  31.03  30.73  29.50  27.36  24.40
BUILDWID  S612  27.36  29.50  30.73  31.03  30.39  28.83
BUILDWID  S612  26.39  23.15  19.20  23.15  26.39  28.83
BUILDWID  S612  30.39  31.03  30.73  29.50  27.36  24.40


** Treat the two sources seperatly
  SRCGROUP  DWTF   DWTF
  SRCGROUP  S612   S612

SO FINISHED

RE STARTING

** Daycare
** Daycare 1
  DISCCART  13007  71051  181
** Daycare 2
  DISCCART  13071  71948  177
** Daycare 3
  DISCCART  12838  72357  171


** Residences
** Ranch House A
  DISCCART  15072  71457  211
** Ranch House B
  DISCCART  15055  70862  223
** Ranch House C
  DISCCART  15066  70923  221
** Residence 1
  DISCCART  14424  73360  177
** Residence 2
  DISCCART  14486  73316  178
** Residence 3
  DISCCART  14565  73197  177
** Residence 4
  DISCCART  15762  72890  202
** Residence 6
  DISCCART  16988  72651  232
** Residence 7
  DISCCART  16592  72427  219
** Residence 8
  DISCCART  16889  71795  241
** Residence 9
  DISCCART  16919  71827  235
** Residence 10
```

```
  DISCCART  16644  71850  221
** Residence 11
  DISCCART  16204  71746  213
** Residence 12
  DISCCART  15762  71765  198
** Residence 13
  DISCCART  15686  71748  198
** Residence 2
  DISCCART  15531  72429  198
** Residence 3
  DISCCART  15171  72064  190
** Residence 4
  DISCCART  15196  72069  190
** Residence 9
  DISCCART  14822  73166  183


** Business
** Credit Union
  DISCCART  14950  71475  189
** Veterinarian
  DISCCART  15035  72154  189
** Filteration Plant
  DISCCART  16986  72712  209
** Industrial park - 1
  DISCCART  14611  72920  182
  DISCCART  14978  72920  187
  DISCCART  14576  72669  181
  DISCCART  14944  72931  186
  DISCCART  14935  73076  186
  DISCCART  14627  73068  183
  DISCCART  14844  72931  185
  DISCCART  14844  73076  185
  DISCCART  14744  72931  183
  DISCCART  14744  73076  183
** Industrial park - 2
  DISCCART  14534  72691  181
  DISCCART  14571  73006  180
  DISCCART  13421  72805  172
  DISCCART  13423  72673  173
  DISCCART  14434  72691  180
  DISCCART  14434  73006  180
  DISCCART  14334  72691  179
  DISCCART  14334  73006  178
  DISCCART  14234  72691  178
  DISCCART  14234  73006  178
  DISCCART  14134  72691  178
```

```
 DISCCART 14134  73006  177
 DISCCART 14434  72849  180
 DISCCART 14334  72849  177
 DISCCART 14234  72849  178
 DISCCART 14134  72849  177
 DISCCART 13785  72666  175
** Industrial park - 3
 DISCCART 13390  72670  173
 DISCCART 13382  72800  172
 DISCCART 13134  72749  171
 DISCCART 13114  72519  172

 GRIDCART  LARGE  STA
           XYINC 12500 21 250 70000 21 250
           ELEV  70000  181     182 183 189 194 201 210
           ELEV  70000  221     215 210 226 241 256 265
           ELEV  70000  275     282 288 295 301 274 286
           ELEV  70250  180     181 183 187 192 198 205
           ELEV  70250  215     211 208 221 234 247 256
           ELEV  70250  265     274 283 292 298 278 287
           ELEV  70500  178     180 182 186 190 195 201
           ELEV  70500  209     207 206 216 227 238 247
           ELEV  70500  256     267 278 289 294 282 289
           ELEV  70750  177     179 181 185 188 193 197
           ELEV  70750  202     203 205 211 220 230 238
           ELEV  70750  246     260 274 286 290 286 291
           ELEV  71000  176     178 180 183 187 190 193
           ELEV  71000  196     200 203 206 214 221 228
           ELEV  71000  236     252 269 282 286 289 293
           ELEV  71250  175     177 179 182 185 187 190
           ELEV  71250  193     196 199 202 209 216 222
           ELEV  71250  229     243 256 270 282 294 292
           ELEV  71500  174     176 178 180 183 185 187
           ELEV  71500  190     192 195 197 204 210 216
           ELEV  71500  223     233 243 258 279 299 291
           ELEV  71750  172     174 176 178 180 183 185
           ELEV  71750  187     189 191 193 199 204 210
           ELEV  71750  216     223 230 246 275 303 291
           ELEV  72000  171     173 175 177 178 180 182
           ELEV  72000  183     185 187 188 194 199 204
           ELEV  72000  210     213 217 234 271 308 290
           ELEV  72250  170     172 174 175 177 179 180
           ELEV  72250  182     184 186 188 193 199 204
           ELEV  72250  209     215 221 236 267 300 291
           ELEV  72500  168     170 172 174 176 177 179
           ELEV  72500  182     184 186 188 193 198 203
```

```
            ELEV  72500  208      216 224 239 263 292 292
            ELEV  72750  167      168 170 172 174 176 178
            ELEV  72750  181      183 186 188 193 198 202
            ELEV  72750  207      217 227 241 259 283 294
            ELEV  73000  165      167 169 171 173 175 177
            ELEV  73000  180      183 185 188 193 197 202
            ELEV  73000  206      219 231 243 256 275 295
            ELEV  73250  164      166 167 169 171 173 175
            ELEV  73250  178      181 184 190 193 205 209
            ELEV  73250  210      220 234 253 274 289 311
            ELEV  73500  163      165 166 168 169 171 173
            ELEV  73500  176      180 184 192 194 212 216
            ELEV  73500  215      221 238 264 292 303 328
            ELEV  73750  162      164 165 166 168 169 171
            ELEV  73750  175      179 183 194 195 220 223
            ELEV  73750  219      222 241 274 310 316 344
            ELEV  74000  161      162 164 165 166 167 169
            ELEV  74000  173      177 182 196 195 228 230
            ELEV  74000  223      223 245 284 328 330 361
            ELEV  74250  161      162 163 165 166 167 169
            ELEV  74250  173      177 181 195 198 223 232
            ELEV  74250  234      244 270 310 343 338 355
            ELEV  74500  160      161 163 164 166 167 169
            ELEV  74500  173      177 181 193 201 219 235
            ELEV  74500  246      265 296 336 358 346 349
            ELEV  74750  159      161 162 164 166 167 169
            ELEV  74750  173      177 181 192 204 214 237
            ELEV  74750  257      287 322 361 373 355 343
            ELEV  75000  158      161 161 164 166 167 169
            ELEV  75000  173      177 181 191 207 209 239
            ELEV  75000  268      309 348 386 388 364 337
   GRIDCART  LARGE  END

** GRIDCART  SMALL  STA
**              XYINC -500 21 50 -500 21 50
** GRIDCART  SMALL  END

** GRIDCART  SMALL  STA
**              XYINC  0       21 50  0 21 50
** GRIDCART  SMALL  END

RE FINISHED

ME STARTING
   INPUTFIL  LLNL95NW.ISC
   ANEMHGHT  10.
```

```
  SURFDATA  1801  1995  LLNL
  UAIRDATA  1801  1995  LLNL
** DAYRANGE  1-10
ME FINISHED

OU STARTING
  RECTABLE  ALLAVE  FIRST
  PLOTFILE  1        DWTF  FIRST  DWTFMAXD.FIL
  PLOTFILE  PERIOD  DWTF  DWTFAVGD.FIL
  PLOTFILE  1        S612  FIRST  DWTFMAXS.FIL
  PLOTFILE  PERIOD  S612  DWTFAVGS.FIL
OU FINISHED
```

7.0   ISC-ST3 Input File for the Two Surface Sources

```
CO STARTING
  TITLEONE  Running the ISC3-ST model for DWTF Project

** Regulatory default options, Rural dispersion, Concentrations at receptors
** Averaging periods for max and average will be 1 hour and the entire year.
** Building height and width are entered for downwash.
** The pollutant is a unit source so that concentrations will be Chi/Q
** List of errors will be written to ERRORS.OUT

  MODELOPT  DFAULT  RURAL  CONC  WETDPLT  DRYDPLT
**       Find maximum hour (1) and whole-period concentrations
  AVERTIME  1       PERIOD
**       Use unit source
  POLLUTID  Unit
**       Specify all heights for sources and receptors
  TERRHGTS  ELEV
**       Please run the model after checking this input file
  RUNORNOT  RUN
**       List of errors will be written to ERRORS.OUT
  ERRORFIL  ERRORS.OUT
CO FINISHED

SO STARTING


** The 612 Area -- 5 by 5 grid = 25 1-m squares, 25m2*0.04g/(sm2)=1.0 g/s
**          name  type    X     Y     Z
  LOCATION  A612  AREA   14763  71105  198
```

```
**         name   rate  height  side
  SRCPARAM  A612   .04    1           5


** The DWTF Area -- 5 by 5 grid = 25 1-m squares, 25m2*0.04g/(sm2)=1.0 g/s
**         name  type    X      Y     Z
  LOCATION  BDWTF  AREA   15091  71111  198
**         name   rate  height  side
  SRCPARAM  BDWTF   .04    1     5


** Treat the two sources seperatly
  SRCGROUP  A612   A612
  SRCGROUP  BDWTF   BDWTF


SO FINISHED


RE STARTING


** Daycare
** Daycare 1
  DISCCART  13007  71051  181
** Daycare 2
  DISCCART  13071  71948  177
** Daycare 3
  DISCCART  12838  72357  171


** Residences
** Ranch House A
  DISCCART  15072  71457  211
** Ranch House B
  DISCCART  15055  70862  223
** Ranch House C
  DISCCART  15066  70923  221
** Residence 1
  DISCCART  14424  73360  177
** Residence 2
  DISCCART  14486  73316  178
** Residence 3
  DISCCART  14565  73197  177
** Residence 4
  DISCCART  15762  72890  202
** Residence 6
  DISCCART  16988  72651  232
** Residence 7
  DISCCART  16592  72427  219
** Residence 8
  DISCCART  16889  71795  241
```

** Residence 9
  DISCCART 16919 71827 235
** Residence 10
  DISCCART 16644 71850 221
** Residence 11
  DISCCART 16204 71746 213
** Residence 12
  DISCCART 15762 71765 198
** Residence 13
  DISCCART 15686 71748 198
** Residence 2
  DISCCART 15531 72429 198
** Residence 3
  DISCCART 15171 72064 190
** Residence 4
  DISCCART 15196 72069 190
** Residence 9
  DISCCART 14822 73166 183

** Business
** Credit Union
  DISCCART 14950 71475 189
** Veterinarian
  DISCCART 15035 72154 189
** Filteration Plant
  DISCCART 16986 72712 209
** Industrial park - 1
  DISCCART 14611 72920 182
  DISCCART 14978 72920 187
  DISCCART 14576 72669 181
  DISCCART 14944 72931 186
  DISCCART 14935 73076 186
  DISCCART 14627 73068 183
  DISCCART 14844 72931 185
  DISCCART 14844 73076 185
  DISCCART 14744 72931 183
  DISCCART 14744 73076 183
** Industrial park - 2
  DISCCART 14534 72691 181
  DISCCART 14571 73006 180
  DISCCART 13421 72805 172
  DISCCART 13423 72673 173
  DISCCART 14434 72691 180
  DISCCART 14434 73006 180
  DISCCART 14334 72691 179
  DISCCART 14334 73006 178

```
   DISCCART  14234  72691  178
   DISCCART  14234  73006  178
   DISCCART  14134  72691  178
   DISCCART  14134  73006  177
   DISCCART  14434  72849  180
   DISCCART  14334  72849  177
   DISCCART  14234  72849  178
   DISCCART  14134  72849  177
   DISCCART  13785  72666  175
** Industrial park - 3
   DISCCART  13390  72670  173
   DISCCART  13382  72800  172
   DISCCART  13134  72749  171
   DISCCART  13114  72519  172

   GRIDCART  LARGE  STA
              XYINC  12500  21  250  70000  21  250
              ELEV  70000  181      182  183  189  194  201  210
              ELEV  70000  221      215  210  226  241  256  265
              ELEV  70000  275      282  288  295  301  274  286
              ELEV  70250  180      181  183  187  192  198  205
              ELEV  70250  215      211  208  221  234  247  256
              ELEV  70250  265      274  283  292  298  278  287
              ELEV  70500  178      180  182  186  190  195  201
              ELEV  70500  209      207  206  216  227  238  247
              ELEV  70500  256      267  278  289  294  282  289
              ELEV  70750  177      179  181  185  188  193  197
              ELEV  70750  202      203  205  211  220  230  238
              ELEV  70750  246      260  274  286  290  286  291
              ELEV  71000  176      178  180  183  187  190  193
              ELEV  71000  196      200  203  206  214  221  228
              ELEV  71000  236      252  269  282  286  289  293
              ELEV  71250  175      177  179  182  185  187  190
              ELEV  71250  193      196  199  202  209  216  222
              ELEV  71250  229      243  256  270  282  294  292
              ELEV  71500  174      176  178  180  183  185  187
              ELEV  71500  190      192  195  197  204  210  216
              ELEV  71500  223      233  243  258  279  299  291
              ELEV  71750  172      174  176  178  180  183  185
              ELEV  71750  187      189  191  193  199  204  210
              ELEV  71750  216      223  230  246  275  303  291
              ELEV  72000  171      173  175  177  178  180  182
              ELEV  72000  183      185  187  188  194  199  204
              ELEV  72000  210      213  217  234  271  308  290
              ELEV  72250  170      172  174  175  177  179  180
              ELEV  72250  182      184  186  188  193  199  204
```

```
          ELEV  72250  209        215 221 236 267 300 291
          ELEV  72500  168        170 172 174 176 177 179
          ELEV  72500  182        184 186 188 193 198 203
          ELEV  72500  208        216 224 239 263 292 292
          ELEV  72750  167        168 170 172 174 176 178
          ELEV  72750  181        183 186 188 193 198 202
          ELEV  72750  207        217 227 241 259 283 294
          ELEV  73000  165        167 169 171 173 175 177
          ELEV  73000  180        183 185 188 193 197 202
          ELEV  73000  206        219 231 243 256 275 295
          ELEV  73250  164        166 167 169 171 173 175
          ELEV  73250  178        181 184 190 193 205 209
          ELEV  73250  210        220 234 253 274 289 311
          ELEV  73500  163        165 166 168 169 171 173
          ELEV  73500  176        180 184 192 194 212 216
          ELEV  73500  215        221 238 264 292 303 328
          ELEV  73750  162        164 165 166 168 169 171
          ELEV  73750  175        179 183 194 195 220 223
          ELEV  73750  219        222 241 274 310 316 344
          ELEV  74000  161        162 164 165 166 167 169
          ELEV  74000  173        177 182 196 195 228 230
          ELEV  74000  223        223 245 284 328 330 361
          ELEV  74250  161        162 163 165 166 167 169
          ELEV  74250  173        177 181 195 198 223 232
          ELEV  74250  234        244 270 310 343 338 355
          ELEV  74500  160        161 163 164 166 167 169
          ELEV  74500  173        177 181 193 201 219 235
          ELEV  74500  246        265 296 336 358 346 349
          ELEV  74750  159        161 162 164 166 167 169
          ELEV  74750  173        177 181 192 204 214 237
          ELEV  74750  257        287 322 361 373 355 343
          ELEV  75000  158        161 161 164 166 167 169
          ELEV  75000  173        177 181 191 207 209 239
          ELEV  75000  268        309 348 386 388 364 337
   GRIDCART  LARGE  END

** GRIDCART  SMALL  STA
**              XYINC  -500 21  50 -500 21 50
** GRIDCART  SMALL  END

** GRIDCART  SMALL  STA
**              XYINC   0        21 50   0 21 50
** GRIDCART  SMALL  END

RE FINISHED
```

```
ME STARTING
  INPUTFIL  LLNL95NW.ISC
  ANEMHGHT  10.
  SURFDATA  1801  1995  LLNL
  UAIRDATA  1801  1995  LLNL
** DAYRANGE  1-10
ME FINISHED

OU STARTING
  RECTABLE  ALLAVE  FIRST
  PLOTFILE  1        A612  FIRST  DWTFMAXA.FIL
  PLOTFILE  PERIOD  A612  DWTFAVGA.FIL
  PLOTFILE  1        BDWTF  FIRST  DWTFMAXB.FIL
  PLOTFILE  PERIOD  BDWTF  DWTFAVGB.FIL
OU FINISHED
```

8.0   Sample of Meterological Data Used as Input to ISC-ST3

File: **LLNL94.ISC**   Format: **(412, 2FP.4, F6.1, I2, 2F7.1)**
Surface Station No.: **1801**   Upper Air Station No.: **1801**
        Name: **LLNL**   Name: **LLNL**
Year: **1994**   Year: **1994**

				Flow	Speed		Speed	Mixing Height (m)

Year	Month	Day	Hour	Vecor	(m/s)	Temp	Class	Rural	Urban
94	1	1	1	31.0	1.00	278.7	6	600.0	600.0
94	1	1	2	230.0	1.00	277.7	5	600.0	600.0
94	1	1	3	7.0	1.00	276.5	6	600.0	600.0
94	1	1	4	302.0	1.00	276.3	6	600.0	600.0
94	1	1	5	143.0	1.00	275.3	6	600.0	600.0
94	1	1	6	348.0	1.00	275.0	6	600.0	600.0
94	1	1	7	189.0	1.00	275.5	6	600.0	600.0
94	1	1	8	49.0	1.00	275.5	6	600.0	600.0
94	1	1	9	192.0	1.00	275.4	5	600.0	600.0
94	1	1	10	229.0	1.00	276.7	4	600.0	600.0
94	1	1	11	28.0	1.00	280.0	3	600.0	600.0
94	1	1	12	91.0	1.39	284.4	2	600.0	600.0
94	1	1	13	291.0	1.00	288.9	1	600.0	600.0
94	1	1	14	134.0	1.00	291.4	1	600.0	600.0
94	1	1	15	161.0	2.59	289.5	2	600.0	600.0
94	1	1	16	214.0	4.60	284.8	3	600.0	600.0
94	1	1	17	213.0	3.89	282.4	4	600.0	600.0
94	1	1	18	197.0	3.62	281.2	4	600.0	600.0
94	1	1	19	218.0	1.70	281.2	4	600.0	600.0
94	1	1	20	219.0	3.31	280.7	4	600.0	600.0
94	1	1	21	220.0	4.78	280.2	5	600.0	600.0
94	1	1	22	224.0	3.89	279.9	4	600.0	600.0
94	1	1	23	225.0	2.68	279.9	4	600.0	600.0
94	1	1	24	225.0	2.82	280.0	4	600.0	600.0

Notes: Stability Class   1 = A,   2 = B,   3 = C,   4 = D,   5 = E,   and   6 = F.
Flow Vector is director toward which wind is blowing.

Supplement C.

Natural and Man-Made Radiation

SUPPLEMENT C. NATURAL AND MAN-MADE RADIATION

1.0   Introduction

Radiological doses to the public result from both natural and man-made radiation. This brief overview of natural and man-made radiation is provided in the Lawrence Livermore National Laboratory (LLNL) *Environmental Report for 1994* (LLNL, 1995) and is repeated here to give the reader a very basic understanding of radiation. For more information, see *Radiation: Doses, Effects, Risks* (U.N. Environment Programme, 1985).

By far the greatest part of radiation received by the world's population comes from natural sources—primarily cosmic rays that impinge on the earth's atmosphere from space and radionuclides naturally present in our environment, such as radioactive materials in soil and rocks. Among these terrestrial sources are carbon-14, potassium-40, rubidium-87, uranium-238, thorium-232, and the radioactive elements, such as radon, that arise following decay of uranium and thorium. The source of human exposure to natural radiation can be external (from substances staying outside the body) or internal (from substances inhaled in air or ingested in food and water). Individual doses vary with location. The level of cosmic radiation increases with altitude because there is less air overhead to act as a shield, and the earth's poles receive more cosmic radiation than the equatorial regions because the earth's magnetic field diverts the radiation. The levels of terrestrial radiation differ from place to place around the United States and around the world, mainly due to variations in soil and rock composition.

Adding to this pervasive natural or background radiation is man-made radiation from radionuclides used in medicine, consumer products, and the production of energy and nuclear weapons. Exposure to man-made sources can be controlled more readily than exposure to most natural sources. However, nuclear explosives tested in the atmosphere in the 1950s–1960s spread radioactivity across the surface of the globe, and the nuclear reactor accident at Chernobyl affected a large area. At present, medical treatment is the largest common source of public exposure to man-made radiation. Individual medical doses vary enormously—someone who has never had an x-ray examination may receive zero medical dose while patients undergoing treatment for cancer may receive many thousands of times the annual average dose from natural radiation. Another source of public exposure to man-made radiation is consumer products, including luminous-dial watches, smoke detectors, airport x-ray baggage inspection systems, and tobacco products.

2.0   Radioactivity

Generally, naturally occurring isotopes are stable, but notable exceptions include carbon-14, potassium-40, thorium-232, uranium-235, and uranium-238, which are naturally occurring but radioactive. Nuclear decay divides into three main categories: alpha, beta, and gamma. Alpha decay is the spontaneous emission of an alpha particle (a bound state of two protons and two neutrons—the nucleus of a helium atom) from a nucleus containing a large number of protons (most commonly 82 or more). Beta decay is the spontaneous conversion of a neutron to a proton

in the nucleus with the emission of an electron, and gamma decay is the spontaneous emission of high-energy photons (high-frequency electromagnetic radiation) by nuclei.

Radioisotopes decay at quite different rates; the "half-life," or length of time for half of the atoms to decay, spans a wide range from small fractions of a second to millions of years. For example, tritium (the radioactive form of hydrogen) has a 12.3-year half-life, compared to 24,131 years for plutonium-239.

Some radioisotopes undergo a decay chain, forming radioisotopes that decay into other radioisotopes until a stable state is achieved. For example, an atom of uranium-238 can undergo alpha decay, leaving behind a daughter, thorium-234, which is also radioactive. The transformations of the decay chain continue, ending with the formation of lead-206, which is a stable isotope.

Radioactivity can be hazardous because radiation (alpha particles, beta particles, or gamma rays) can be released with great energy. It is capable of altering the electronic configuration of atoms and molecules, especially by stripping one or more electrons off the atoms of the irradiated material, thereby disrupting the chemical activity in living cells. If the disruption is severe enough to overwhelm the normal restorative powers of the cell, the cell may die or become permanently damaged. Cells are exposed to many naturally occurring sources of chemical disruption, including naturally toxic chemicals in food, microbes that cause disease, high-energy radiation from outer space (cosmic rays), and heat and light (including the sun's rays, which can cause sunburn and skin cancer). Consequently, cells and living organisms have evolved the capacity to survive limited amounts of damage, including that caused by naturally occurring radioactivity.

Three main factors determine the radiation-induced damage that might be caused to living tissue: the number of radioactive nuclei that are present, the rate they give off energy, and the effectiveness of energy transfer to the host medium, i.e., how the radiation interacts with the tissue. Alpha radiation can be halted by a piece of paper and can scarcely penetrate the dead outer layers of skin. Radioisotopes that give off alpha radiation are generally not health hazards unless they get inside the body through an open wound or are ingested or inhaled. In those cases, alpha radiation can be especially damaging because its disruptive energy can be deposited within a small distance, resulting in significant energy deposited in a few cells. Beta radiation from nuclear decay typically penetrates a centimeter or two of living tissue. It therefore deposits energy over many cells, decreasing the damage to any single cell. Gamma radiation is extremely penetrating and can pass through most materials, only being significantly attenuated by thick slabs of dense materials, such as lead.

3.0   Measurement of Radioactivity and Dose

The rate that a nucleus decays is expressed in units of becquerels, abbreviated Bq, where one becquerel is one decay per second, or alternatively in curies, Ci, where one curie equals 3.7×10^{10} (37 billion) decays per second, or 3.7×10^{10} Bq (approximately equal to the decay rate of 1 gram of pure radium). Becquerels and curies are not measures of the effect of radiation

on living tissue. This depends on the efficiency of energy deposition as the radiation traverses matter.

The amount of energy deposited in living tissue is called the "dose." The amount of radiation energy absorbed per gram of tissue is called the "absorbed dose," and is expressed in units of rads or grays (Gy), where 1 Gy equals 100 rads. Because an absorbed dose produced by alpha radiation is more damaging to living tissue than the same dose produced by beta or gamma radiation, the absorbed dose is multiplied by a quality factor to give the dose equivalent. The quality factor for alpha radiation is 20; for beta and gamma, 1. The dose equivalent is measured in units of rem or Sievert (Sv); 1 Sv equals 100 rem. Also commonly used are millirem (mrem) and milliSievert (mSv), which are one-thousandth of a rem and sievert, respectively.

Just as one type of radiation can be more damaging than others, some parts of the body are potentially more vulnerable to radiation damage than others, so the different parts of the body are given weightings. For example, a given radiation dose from iodine-131 is more likely to cause cancer in the thyroid than in the lung. The reproductive organs are of particular concern because of the potential risk of genetic damage. Once particular organs are weighted appropriately, the dose equivalent becomes the "effective dose equivalent," also expressed in rem or sievert.

The effective dose equivalent describes doses to individuals. When individual effective dose equivalents received by a group of people are summed, the result is called the "collective effective dose equivalent" and is expressed in person-Sievert or person-rem. Finally, to account for the long-term effects of radionuclides as they continue to decay and affect generations of people, we calculate the dose over many years, summing the effect over time. This is termed the "collective effective dose equivalent commitment." Most of our discussion in this chapter deals with the effective dose equivalent and the collective effective dose equivalent.

4.0   Doses from Natural and Man-Made Radioactivity

The average radiation dose from natural sources in the United States, according to the National Council on Radiation Protection and Measurement (NCRPM, 1987), is 3.0 mSv/y (300 mrem/y). Approximately 0.3 mSv/y (30 mrem/y) of this exposure comes from high energy radiation from outer space (cosmic rays). Terrestrial sources, mainly radionuclides in rock and soil, also account for approximately 0.3 mSv/y (30 mrem/y) of the average natural dose. Another significant part of the dose comes from radionuclides we ingest through food and drink, resulting in approximately 0.4 m Sv/y (40 mrem/y). Potassium-40 and carbon-14 are common radionuclides in food.

The remaining 2.0 mSv/y (200 mrem/y) or 67% of the average dose from natural sources in the United States comes from radon gas. Radon is one of the major radionuclides produced by uranium decay, and our inhalation dose is dominated by radon's short-lived decay products. **Figure G-1** shows the distribution of annual radiation doses from natural and other common sources.

Radon dose varies significantly with geographic location. Levels several times higher than the average occur in some regions of the United States while at LLNL and its environs doses as low

as half the average are typical. Radon gas seeps out of the earth worldwide. Radon in water and natural gas provide additional but less important sources of radon in homes. Consumption of water high in radon is not the main exposure source; a greater exposure is believed to arise from inhalation of radon in water vapor when showering. The United States Environmental Protection Agency (EPA) has instituted a major program to educate the public regarding the effects of naturally occurring radon (EPA and U.S. Department of Health and Human Services, 1986).

Medical treatment is the largest common source of public exposure to man-made radiation, and most of it is from medical x-rays. These contribute 0.39 mSv (39 mrem) to the average whole-body dose in the United States, but individual doses vary enormously. For example, a typical dental x-ray series results in a skin dose (not whole body) of approximately 2.5 mSv (250 mrem). Nuclear medicine contributes 0.14 mSv (14 mrem) to the average dose, and consumer products add 0.1 mSv (10 mrem). For a typical member of the public, radiation from medical procedures and consumer products result in a dose of approximately 0.63 mSv/y (63 mrem/y). The average dose from other man-made sources, including fallout from nuclear testing, is less than 0.03 mSv (3 mrem). As will be described in the following sections, the contributions from LLNL operations to the dose of even the most affected resident would not be discernible on the scale shown in **Figure G-1**; see the *Environmental Report for 1994* (Harrach *et al.*, 1994) for further discussion of LLNL contributions to dose.

5.0   References

Harrach, R.J., R.A. Failor, G.M. Gallegos, P.J. Tate, E. Christofferson, E.R. Brandstetter, J.M. Larson, A.H. Biermann, R.A. Brown, B.C. Fields, L.M. Garcia, and A.R. Grayson. 1995. *Environmental Report 1994.* Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50027-94.

National Council on Radiation Protection and Measurement (NCRPM). 1987. *Ionizing Radiation Exposure of the Population of the United States,* Report No. 93, National Council on Radiation Protection and Measurements, Washington, D.C.

U.N. Environment Programme. (1985). *Radiation: Doses, Effects, Risks.* United Nations Environment Programme, Nairobi, Kenya (Sales No. E.86.III.D.4).

U.S. Environmental Protection Agency (EPA) and U.S. Department of Health and Human Services. 1986. *A Citizen's Guide to Radon: What It Is and What to Do about It.* U.S. Environmental Protection Agency, Office of Air Public Awareness, Washington, D.C. (Pamphlet No. OPA 86-004).

6.0   Acronyms

EPA   Environmental Protection Agency

LLNL   Lawrence Livermore National Laboratory

NCRPM   National Council on Radiation Protection and Measurement
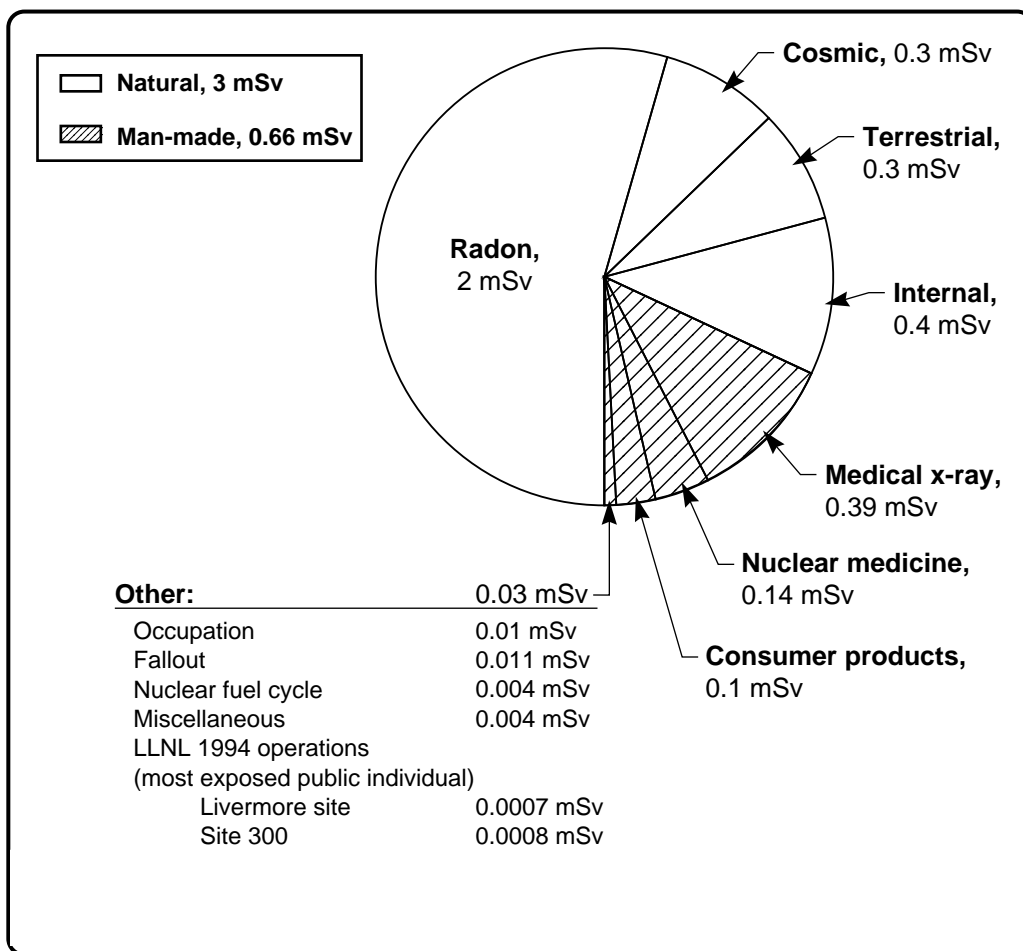
U.S.   United States

Figure C-1.   Typical annual radiation doses from natural and man-made sources (NCRPM, 1987)

Supplement D.

Assessment of Potential Risks to Ecological Resources

SUPPLEMENT D. ASSESSMENT OF POTENTIAL RISKS TO ECOLOGICAL RESOURCES

1.0   Introduction

This Appendix provides a qualitative screening assessment of potential ecological risks resulting from hazardous waste management facilities at the Main Site of Lawrence Livermore National Laboratory (LLNL) as described in **Section II**. This assessment evaluated an area of approximately 12 mi^2 (20 km^2) with the LLNL Main Site at its approximate center.

2.0   Environmental Setting

As part of the overall health risk assessment, we performed a qualitative screening assessment of potential risks to ecological resources resulting from hazardous waste management operations at LLNL's Main Site. Previous local area investigations identified potential target species, and the sections below discuss the probable magnitude of effects, if any, on these species that could result from exposures to the Chemicals of Potential Concern (COPCs).

2.1   Location

Information regarding the location, historic land uses, and current major programs was largely adapted from the August 1992 Final Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore (1992 EIS/EIR) (DOE, 1992). Information regarding topography and climate were taken from the *Annual Environmental Report for 1993* (Gallegos, *et al.*, 1994).

The LLNL Main Site is located approximately 40 mi (64.4 km) east of San Francisco at the southeastern end of the Livermore Valley in southern Alameda County (**Figure A-1**).

The LLNL Main Site, which is adjacent to the City of Livermore, occupies essentially all of Section 12, T3S, and R2E (USGS Altamont quadrangle), and a portion of Sections 1, 2, and 11 for a total area of 820 acres (330 hectares). Lands to the north are zoned industrial, lands to the east and south are zoned mostly agricultural, and lands to the west are zoned residential.

2.2   Historic Land Uses and Current Laboratory Programs

2.2.1   Historic Land Uses

Before World War II, the present-day LLNL Main Site was part of the Wagoner Ranch; cattle grazing was the dominant land use. The U.S. Navy purchased the site in 1942 and established the Livermore Naval Air Station as a flight training base. Runways were constructed near the center of the site with a rectangular-grid street system along the southern portion of the site (University of California [UC], 1987).

The transition from Navy operations to a research facility began in 1950 when the California Research and Development Corporation (a subsidiary of Standard Oil, Inc.) began construction of the Materials Test Accelerator facility, as authorized by the U.S. Atomic Energy Commission. In 1951, the University of California Radiation Laboratory in Berkeley began using some of the Livermore facilities in support of nuclear weapons research being conducted by the Los Alamos Scientific Laboratory in New Mexico (UC, 1987).

2.2.2   Current Major Programs

Today LLNL is a multiprogram national laboratory operated by UC for the U.S. Department of Energy (DOE). It undertakes multidisciplinary fundamental and applied research and development activities in a broad range of scientific and technical fields and maintains close interaction with scientific and technical personnel within universities and industry. LLNL's primary mission has always been the design of nuclear weapons; however, major new research programs have been developed in response to national needs. Major research programs include defense systems, laser fusion, laser isotope separation, magnetic fusion, biomedical and environmental research, environmental and waste management, and energy resources. In addition, LLNL has a number of multiprogram and general purpose facilities that support all Laboratory programs.

2.3   Topography

The LLNL Main Site is located in an east-west-oriented depression within the Diablo Range of the California Coast Province. The Livermore Valley, the most prominent valley within the Diablo Range, is an east-west trending trough that is bounded on the west by Pleasanton ridge and on the east by the Altamont Hills. The valley floor is covered by alluvial, lake, and swamp deposits consisting of gravels, sands, silts, and clays, with an average thickness of about 328 ft (100 meters). The valley is approximately 15 mi (25 km) long and averages 7 mi (11 km) wide and ranges in elevation from 720 ft (220 m) above mean sea level along the eastern margin and gradually dips to 302 ft (92 m) at the southwest corner.

2.4   Climate

Mild, rainy winters and warm, dry summers characterize the climate of the Livermore Valley. The mean annual temperature for 1993 was 15° C. Temperatures range from -5° C during pre-dawn winter mornings to 40° C during summer afternoons. Meteorological data, wind speed, wind direction, rainfall, and temperature measurements are gathered at the Main Site.

Both rainfall and wind exhibit a strong seasonal pattern. The prevailing winds are from the west and south-southwest, accounting for over 50 percent of the wind pattern. These wind patterns are controlled by the thermal draw of the warm Central Valley that results in wind blowing from the cool ocean toward the warm valley, increasing in intensity as the valley heats up. The wind blows from the northeast primarily during the winter storm season. Most precipitation occurs between October and April, with very little rainfall during the warmer months. The highest and lowest annual rainfalls on record are 31 in. (782 mm) and 5 in. (138 mm). In 1993, the Main Site received 16 in. (402 mm) of rain.

2.5   Ecological Setting

Approximately 78 percent of the LLNL Main Site has been developed (DOE, 1992). Vegetation at this site has been altered by past land uses, including livestock grazing from the 1800s to the mid-1900s, the development of the Livermore Naval Air Station beginning in 1942, and further development of the site as the Livermore Radiation Laboratory and subsequently as LLNL. Surrounding the LLNL Main Site are areas developed as agricultural, light industrial, and residential.

Immediately to the south of LLNL's Main Site is Sandia National Laboratories, Livermore (now Sandia Laboratories, California [SNL/CAL]), operated by Martin-Marietta under DOE contract. SNL/CAL occupies 413 acres (1,020 hectares). It provides research and development associated with nuclear weapons systems engineering as well as related national security tasks. Although their primary missions are similar, LLNL and SNL/CAL are separate facilities, each with its own management and each reporting to a different DOE operations office.

2.5.1   Area Assessed

For the purposes of this assessment, we evaluated an area consisting of approximately 12 mi^2 (20 km^2) with the LLNL Main Site at its approximate center (**Figure D-1**). This area includes sections 6, 7, and 18 T3S, R3E, and sections 1, 2, 11, 12, 13, and 14, T 3S, R2E. We selected this area to conform with guidance provided in the *Preliminary Endangerment Assessment (PEA) Guidance Manual* produced in 1994 by the California Environmental Protection Program, Department of Toxic Substances Control (CAL/EPA/DTSC, 1994) to characterize biological resources potentially occurring at the project site: "due to their occurrence at nearby areas (i.e., within 1 mile)."

2.5.2   Current Land Uses

The LLNL Main Site and SNL/CAL include developed areas (laboratories and other buildings and facilities) surrounded by security zones of mostly grassland. The least disturbed habitat is along Arroyo Seco, which runs through the SNL/CAL site and the southwestern corner of the LLNL Main Site. Three distinct vegetation types were identified at SNL/CAL along this arroyo and include a remnant of riparian, riparian understory, and wetlands vegetation.

The developed areas at the LLNL Main Site are planted with ornamental vegetation and lawns. There are also small areas of disturbed ground with early successional plant species. The undeveloped land in the security zone consists of the introduced annual grassland plant community dominated by non-native grasses, such as slender oat and ripgut brome. A relatively undisturbed plant community at the LLNL Main Site is a remnant of the native, wooded riparian plant community along Arroyo Seco. At the LLNL Main Site, Arroyo Seco is steep-sided, with the slopes covered with grass species, such as slender oats and ripgut brome. Much of the arroyo has native tree species, such as red willow and California walnut, and introduced species, such as black locust and almond.

Land use in the surrounding area includes agriculture (primarily livestock grazing) and rural residential to the east and south; viticulture and low-density residential to the south and

southwest; low- and medium-density residential, light industrial, professional business park, neighborhood and freeway commercial, open space/park, and public use (schools, city services, etc.) to the west and northwest (**Figure D-2**). Land to the north is zoned industrial.

2.6   Ecological Resources

We reviewed several sources to determine plant and animal species that have been observed on and surrounding the LLNL Main Site and SNL/CAL (McIntyre, 1977; DOE, 1982; DOE, 1992; UC, 1986; and Woollett, 1995). A summary of information contained in these documents is presented below.

2.6.1   Plants

Lists of plant species occurring at the LLNL and SNL/CAL sites have been reported in several documents (McIntyre, 1977; DOE, 1982; UC, 1986; and DOE, 1992). Approximately 114 species in 52 families of both naturally-occurring and horticultural plants have been identified. The dominant vegetation type present in undisturbed areas is introduced annual grasses. Dominant plant species include ripgut brome (*Bromus diandrus*), slender oats (*Avena barbata*), star thistle (*Centaurea solstitialis*), Russian thistle (*Salsola kali*), turkey mullein (*Eremocarpus setigeris)*, alfalfa (*Medicago sativa*), sweet fennel (*Foeniculum vulgare)*, California sagebrush (*Artemisia california*), and Italian ryegrass (*Lolium multiflorum*) (DOE, 1992). A more complete list of plant species reported for the LLNL Main Site can be found in the 1986 draft *Environmental Impact Report* (UC, 1986).

2.6.2   Wildlife

Lists of wildlife species occurring at the LLNL and SNL/CAL sites have also been reported in several documents (McIntyre, 1977; DOE, 1982; DOE, 1992; and UC, 1986). In 1992, a total of 10 species of mammals, 31 species of birds, 1 species of amphibian, and 2 species of reptiles were observed during surveys of the LLNL and SNL/CAL sites (DOE, 1992). Earlier reports (McIntyre, 1977; DOE, 1982; and UC, 1986) list additional mammal, bird, amphibian, and reptile species as occurring on the site, but it is unclear whether these lists represent actual observations of the species onsite or a combination of observations and additional species potentially occurring on the sites.

Recent observations of additional species have been well documented (Woollett, 1995). A total of 24 bird species not included on previous lists and 11 birds not seen in the 1991 surveys have been observed in 1994–1995. One amphibian species not previously included on species lists, the California tiger salamander, was also observed in 1994. These additional observations were made by a qualified wildlife biologist during project-specific surveys or coincidentally with other projects.

A pair of gray foxes are resident on the LLNL Main Site and successfully raised a litter of pups in 1995. These foxes are apparently using the crawl space under office trailers for denning, and forage in the landscaped and natural areas within the LLNL Main Site. The storm water retention basin is filled with water year-round and provides resting and foraging habitat for a variety of migrant waterfowl. The north and west buffer zones also provide excellent foraging

habitat for a variety of species, including northern loggerhead shrikes, sharp-shinned hawks, American kestrels, and burrowing owls.

2.7 Sensitive Ecological Resources

We considered sensitive ecological resources to include species listed as threatened, endangered, or candidates for threatened or endangered status pursuant to the federal Endangered Species Act, species considered threatened or endangered pursuant to the California Endangered Species Act, species considered by the California Department of Fish and Game (DFG) to be species of special concern and fully protected species, and wetlands and riparian habitat. **Table D-1** is a list of special status species which may occur in the LLNL vicinity (DFG, 1995, and U.S. Fish and Wildlife Service [FWS], 1996). **Figure D-1** shows the known locations of sensitive resources at and surrounding the LLNL and SNL/CAL sites.

2.7.1 Threatened, Endangered, and Other Protected Species

No species listed as threatened or endangered pursuant to the California or federal Endangered Species Act are known to occur at the LLNL and SNL/CAL sites, but the area is considered potential habitat for the San Joaquin kit fox (federal endangered, state threatened), and the arroyos and wetlands on site are potential habitat for the red-legged frog (federal threatened species and state species of special concern) and the California tiger salamander (federal candidate species and state species of special concern). Based on the lack of evidence that any threatened or endangered species occurred at the LLNL Main Site, the U.S. Fish and Wildlife Service determined that continuing operations at LLNL would not adversely affect listed species (FWS, 1992). In 1994, the California red-legged frog (federal threatened species and state species of special concern) was observed approximately 0.8 mi (1.3 km) east-northeast of the proposed Decontamination and Waste Treatment Facility (DWTF) site (**Figure D-1**). In addition, 13 special-status species have been observed at the LLNL and SNL/CAL sites between 1991 and 1995. Two are listed as "fully protected birds" (California Fish and Game Code 3511), and ten are listed as either federal candidate species or as state species of special concern.

Two special-status species of birds have been observed nesting on the LLNL Main Site. Two pairs of burrowing owls have been observed in a relatively undisturbed area along the northern boundary of the LLNL Main Site, known as the north buffer zone, just north of LLNL hazardous waste management facilities (**Figure D-1**). A pair of white-tailed kites have nested in the east-central portion of the LLNL Main Site less than 0.5 mi (0.8 km) from LLNL hazardous waste management facilities (**Figure D-1**) and successfully fledged young in 1994 and 1995.

2.7.2 Wetlands, Seasonal Streams, and Riparian Habitat

Wetlands at the LLNL and SNL/CAL sites are located along Arroyo Las Positas, Arroyo Seco, the drainage retention basin, percolation ponds, and at various small locations generally associated with chronic water discharges at cooling towers and other facilities. A total of 1.8 acres of wetlands at five locations were noted in the 1992 EIS/EIR for the LLNL (three sites totaled 0.36 acres) and SNL/CAL (two other sites had a total of 1.44 acres) Livermore sites (DOE, 1992). These totals do not include the retention basin and the other small, facility-associated wetlands, or the expansion of wetlands habitat occurring in Arroyo Los Positas in the

last two years. Remnants of wooded riparian vegetation occurs at the wetlands along Arroyo Seco.

3.0   Ecological Risk Assessment

3.1   Pathway Analysis

Regarding the potential pathways of exposure to contaminants, we assumed that potential exposure would result from ingestion or dermal absorption of material deposited from airborne emissions. Airborne transmission of COPCs is the primary exposure pathway for the human health portion of this risk assessment. As indicated in **Section 2.4**, the prevailing winds are from the west and southwest, accounting for 45 percent of the wind pattern. The wind also blows from the northeast, primarily during the winter storm season.

3.2   Contaminants of Concern

Section III of this report discusses the toxic air contaminants potentially of concern. We did not consider potential accumulation, bioaccumulation, or bioconcentration of contaminants.

3.3   Potential Effects to Ecological Resources

Based on available information regarding occurrence and use by wildlife species at the LLNL and SNL/CAL sites, and the surrounding areas, we conclude that hazardous waste management activities associated with ongoing operations at LLNL Main Site, and this proposed action would not appear to have significant or measurable adverse effects on local ecological resources. The ecological resources of the LLNL and SNL/CAL sites have not been monitored in detail; however, information gathered over several years indicates that species diversity has not been negatively affected by site operations. No significant deterioration of habitats, species diversity, or numbers has been noted in numerous field studies. In fact, there are some indications that LLNL operations have improved overall habitat and species diversity from what existed when the site was occupied by the Livermore Naval Air Station (McIntyre, 1977).

Sensitive ecological resources that are located within approximately 1.0 mi (1.6 km) of LLNL's hazardous waste management facilities are as follows: nesting white-tailed kites approximately 0.5 mi (0.8 km) south, burrowing owls less than 0.5 mi (0.8 km) north, California red-legged frog and California tiger salamander 0.8 mi (1.3 km) east and 1.5 mi (2.4 km) south respectively, and the occurrence of a wide-range of other wildlife and plant species at the LLNL Main Site. Although these recorded observations cannot alone support a conclusion that the LLNL Main Site is now used by a greater diversity of species than in the past, these observations suggest that continuing operations, including hazardous waste management operations, at the LLNL Main Site, are not negatively affecting sensitive ecological resources or species diversity.

3.4   Conclusion Concerning Ecological Risk Assessment

Based on available information regarding occurrence of diverse flora and fauna and the viability of species living at LLNL and the surrounding areas, and the use by wildlife species of the LLNL and SNL/CAL sites and the surrounding areas, we conclude that LLNL's hazardous waste

management activities do not appear to have significant or measurable adverse effects on local ecological resources. From this qualitative screening assessment, further investigation concerning toxic effects of the chemicals of concern, potential pathways for exposure, potential accumulation or concentration in the environment and biota, or possible individual-, population-, or ecosystem-level effects is not warranted at this time.

4.0   References

California Department of Fish and Game (DFG). 1995. Letter from Ken Aasen, DFG, to Ken Zahn, Environmental Protection Department, Lawrence Livermore National Laboratory, Subject: "Special status species list, LLNL Main Site and Site 300." October 12.

California Environmental Protection Program, Department of Toxic Substances Control (CAL/EPA/DTSC). 1994. *Preliminary Endangerment Assessment (PEA) Guidance Manual.* State of California Environmental Protection Agency, Department of Toxic Substances Control, Sacramento, CA, January.

Fish and Wildlife Service (FWS), U.S. Department of the Interior. 1992. Letter from Wayne White, Field Supervisor, to Anthony Adduci, DOE Project Manager. Subject: "Endangered Species Act Compliance for Continued Operations of Lawrence Livermore National Laboratory/Sandia National Laboratories, Livermore, Alameda County, CA." February 20.

Fish and Wildlife Service (FWS), U.S. Department of the Interior. 1995. Letter from Joel Medlin, FWS, to Ken Zahn, Environmental Protection Department, LLNL. Subject: "Request for updated species list for LLNL Main Site and LLNL Site 300, Alameda County, CA."

Gallegos, G.M., P.J. Tate, B.K. Balke, E. Christofferson, R.J. Harrach, W.G. Hoppes, R.A. Failor, S.M. Wander, B.C. Fields, L.M. Garcia, and A.R. Grayson. 1994. *Environmental Report for 1993.* Lawrence Livermore National Laboratory, Livermore, September, UCRL-50027-93.

McIntyre, David R. 1977. *Ecology of Lawrence Livermore National Laboratory.* Lawrence Livermore National Laboratory, Livermore, CA, March, UCRL-51987.

U.S. Department of Energy (DOE) and the University of California (UC). 1992. *Final Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore*, Lawrence Livermore National Laboratory, Livermore, CA, August, DOE/EIS-0157, UC EIR SCH# 90030847.

U.S. Department of Energy (DOE). 1982. *Final Environmental Impact Statement, Lawrence Livermore National Laboratory and Sandia National Laboratories— Livermore Sites.* U.S. Department of Energy, Washington, D.C., July, DOE/EIS-0028, UC-2, 11.

University of California (UC). 1986. *Draft Environmental Impact Report for the University of California Contract with the Department of Energy for Operation and Management of Lawrence Livermore National Laboratory.* University of California, Berkeley, CA, December, SCH-85112611.

University of California (UC). 1987. *Final Environmental Impact Report for the University of California Contract with the Department of Energy for Operation and Management of Lawrence Livermore National Laboratory.* University of California, Berkeley, CA, July, SCH-85112611.

Woollett, J.S. 1995. Wildlife biologist. Environmental Evaluations Group, Environmental Protection Department. Memorandum M-003-95/JSW. Lawrence Livermore National Laboratory, Livermore, CA, January 12.

5.0   Acronyms

|	
CAL/EPA	California Environmental Protection Agency
CNPS	California Native Plant Society
COPC	Chemicals of Potential Concern
DFG	(California) Department of Fish and Game
FWS	Fish and Wildlife Service, U.S. Department of the Interior
DOE	U.S. Department of Energy
DTSC	Department of Toxic Substances Control
LLNL	Lawrence Livermore National Laboratory
PEA	Preliminary Endangerment Assessment
SNL/CAL	Sandia National Laboratories, California
SSC	(California) Species of Special Concern
UC	University of California
USGS	U.S. Geological Survey
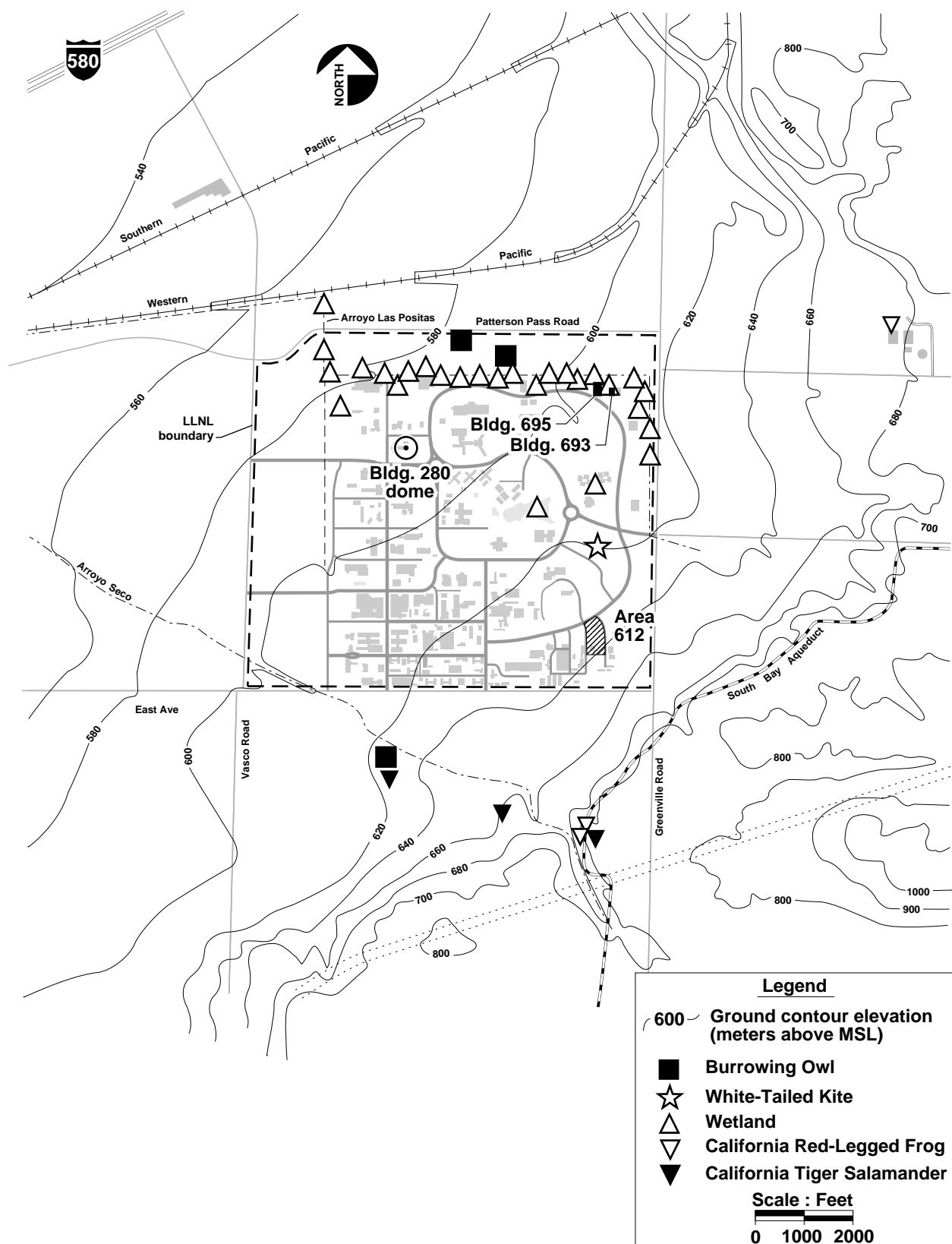
Figure D-1. **Ecological Assessment Area with the LLNL Main Site at its Approximate Center**

Figure D-2.   Land Use in the Area Surrounding LLNL and SNL/CAL

Table D-1. Special Status Species Which May Occur in the Vicinity of LLNL

Common name	Scientific name	Federal status[a]	State status[b]
Mammals			
Greater western mastiff bat	*Eumops perotis californicus*	Former Candidate 2	SSC
Small-footed myotis bat	*Myotis ciliolabrum*	Former Candidate 2	
Long-eared myotis bat	*Myotis evotis*	Former Candidate 2	
Fringed myotis bat	*Myotis thysanodes*	Former Candidate 2	
Long-legged myotis bat	*Myotis volans*	Former Candidate 2	
Yuma myotis bat	*Myotis yumanensis*	Former Candidate 2	
Pacific western big-eared bat	*Plecotus townsendii townsendii*	Former Candidate 2	SSC
Ripariuan brush rabbit	*Sylvilagus bachmani riparius*	Candidate	Endangered
San Joaquin Valley woodrat	*Neotoma fuscipes riparia*	Candidate	SSC
San Francisco dusky-footed woodrat	*Neotoma fuscipes annectens*	Former Candidate 2	SSC
San Joaquin pocket mouse	*Perognathus inornatus*	Former Candidate 2	SSC
San Joaquin kit fox	*Vulpes macrotis mutica*	Endangered	Threatened
American badger	*Taxidea taxus*		SSC
Mountain lion	*Felis concolor*		Protected
Birds			
American peregrine falcon	*Falco peregrinus anatum*	Endangered	Endangered
Bald eagle	*Haliaeetus leucocephalus*	Threatened	Endangered
Golden eagle	*Aquila chryseatos canadensis*	Protected	Protected/SSC
Prairie falcon	*Falco mexicanus*		SSC
Cooper's hawk	*Accipiter cooperi*		SSC
Sharp-shinned hawk	*Accipiter striatus velox*		SSC
Merlin	*Falco columbarius*		SSC
White-tailed kite	*Elanus leucurus*		Protected
Western burrowing owl	*Athene cunicularia hypugea*	Former Candidate 2	SSC
Short-eared owl	*Asio flammeus*		SSC
Long-eared owl	*Asio otus*		SSC
Northern harrier	*Circus cyaneus*		SSC
Swainson's hawk	*Buteo swainsoni*		Threatened
Ferruginous hawk	*Buteo regalis*	Former Candidate 2	SSC
Double-crested cormorant	*Phalocrocrax auritis albociliatus*		SSC
Mountain plover	*Charadrius montanus*	Candidate	
Loggerhead shrike	*Lanius ludovicianus*		SSC

continued on next page

Table D-1. Continued

Common name	Scientific name	Federal status[a]	State status[b]
Birds (continued)			
Horned lark	*Eremophilia alpestris actia*		SSC
Tricolored blackbird	*Agelaius tricolor*	Former Candidate 2	SSC
Little willow flycatcher	*Empidonax traillii brewsteri*	Former Candidate 2	
Bell's sage sparrow	*Amphispiza belli belli*	Former Candidate 2	SSC
Reptiles and Amphibians			
California tiger salamander	*Ambystoma californiense*	Candidate	SSC
California red-legged frog	*Rana aurora draytoni*	Threatened	SSC
Foothill yellow-legged frog	*Rana boylii*	Former Candidate 2	
Western spadefoot toad	*Scaphiopus hammondi*	Former Candidate 2	SSC
Northwestern pond turtle	*Clemmys marmorata marmorata*	Former Candidate 2	SSC
Southwestern pond turtle	*Clemmys marmorata pallid*	Former Candidate 2	SSC
Silvery legless lizard	*Anniella pulchra pulchra*	Former Candidate 2	SSC
California horned lizard	*Phrynosoma coronatum frontale*	Former Candidate 2	SSC
Giant garter snake	*Thamnophis gigas*	Threatened	Threatened
Alameda whipsnake	*Masticophis lateralis euryxanthus*	Proposed End	Threatened
San Joaquin whipsnake	*Masticophis flagellum ruddocki*	Former Candidate 2	SSC
Invertebrates			
Longhorn fairy shrimp	*Branchinecta longiantenna*	Endangered	
Vernal pool fairy shrimp	*Branchinecta lynchi*	Threatened	
Vernal pool tadpole shrimp	*Lepidurus packardi*	Endangered	
Valley elderberry longhorn beetle	*Desmocerus californicus dimorphus*	Threatened	SSC
Curved-foot hygrotus diving beetle	*Hygrotus curvipes*	Former Candidate 2	
Plants			
Large-flowered fiddleneck	*Amsinckia grandiflora*	Endangered	Endangered
Showy Indian clover	*Trifolium amoenum*	Proposed End	
Diamond-petaled poppy	*Eschscholzia rhombipetala*	Former Candidate 2	
Caper-fruited tropidocarpum	*Tropidocarpum capparideum*	Former Candidate 2	
Palmate-bracted bird's beak	*Cordylanthus palmatus*	Endangered	Endangered
Hispid bird's-beak	*Cordylanthus mollis ssp. hispidus*	Former Candidate 2	

Table D-1. Continued

Common name	Scientific name	Federal status[a]	State status[b]
Plants (continued)			
Heartscale	*Atriplex cordulata*	Former Candidate 2	
Valley spearscale	*Atriplex joaquiniana*	Former Candidate 2	
Brittlescale	*Atriplex depressa*	Former Candidate 2	
Little mousetail	*Myosurus minimus ssp. apus*	Former Candidate 2	
Stinkbells	*Fritillaria agrestis*		SSC
Alkali milk vetch	*Astragalus tener tener*		SSC
Big scale balsamroot	*Balsamorhiza macrolepis var. macrolepis*		SSC
Congdon's tarplant	*Hemizonia parryi ssp. congdonii*		SSC
Sharsmith's onion	*Allium sharsmithae*		
Big tarplant	*Blepharizonia plumosa ssp. plumosa*		
Mt. Hamilton thistle	*Cirsium fontinale var. campylon*		
Santa Clara red ribbons	*Clarkia concinna spp. automixa*		
Hospital canyon larkspur	*Delphinium californicum ssp. interius*		
Mt. Diablo buckwheat	*Eriogonum truncatum*		
Talus fritillary	*Fritillaria falcata*		
Hairless popcorn-flower	*Plagiobothrys glaber*		

CNPS = California Native Plant Society

SSC = Special-status species of concern (California).

[a]   FWS, 1995.

[b]   DFG, 1995.